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RESEARCH MEMORANDUM

PRELIMINARY TANK TESTS OF SOME HYDRO-SKI—WHEEL COMBINATIONS IN THE PLANING CONDITION

By Norman S. Land and Rudolph E. Fontana

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
October 6, 1952

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PRELIMINARY TANK TESTS OF SOME HYDRO-SKI—WHEEL COMBINATIONS IN THE PLANING CONDITION

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SUMMARY

An investigation was made of the planing characteristics of various combinations of a wheel and a hydro-ski. The models that were tested included at least two values of the following parameters: Diameter of wheel, width of wheel, cross-section shape of wheel, fore-and-aft location of wheel, lateral location of wheel, gap between wheel and ski, rotation of wheel, and protrusion of wheel. The data gathered are presented in the form of plots of resistance, trimming moment, and wetted length against speed at various values of load and trim. The results of the investigation indicate that the resistance penalty due to a wheel protruding through the ski is highest when the wheel is emerging from the water. The resistance of a wheel and hydro-ski increased continuously with speed if it was not possible for the wheel to emerge. The "fairness" of the protruding portion of the wheel had a large influence on the resistance increase due to the wheel. An increase in width of protrusion of the wheel resulted in marked increase in resistance. A gap between the wheel and ski increased the resistance. Moving the wheel aft resulted in successively higher peak values of resistance.

INTRODUCTION

The experiments of All American Airways, Inc. (ref. 1) have indicated that hydro-skis when combined with relatively small wheel inserts enable a land-based airplane, with no flotation gear, to use adjacent water as a runway. In this type of operation the airplane makes a take-off by entering the water from a small beach or ramp at a low speed and completes the take-off on the water. Landings are conducted in the reverse sense. Since hydro-skis are retractable, this type of landing gear offers the possibility of high-performance airplanes that will not require long runways with their vulnerability and high cost. In addition, an airplane so equipped avoids many of the troubles in maintenance and operation associated with completely water-based airplanes that are difficult to bring ashore.

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Because of the current interest in hydro-ski and wheel combinations, a preliminary tank investigation has been made of the effects of various wheel arrangements on planing characteristics of a flat rectangular hydro-ski.

MODELS AND APPARATUS

Pertinent dimensions and sketches of the models that were tested are given in figure 1. All the tests were made with a flat-bottomed planing surface of rectangular plan form (Langley tank model 291). This model was constructed of mahogany, had a beam of 2.5 inches, a length of 20 inches, and a length-beam ratio of 8. Most of the wheel-ski combinations tested represented a center-line wheel protruding through the ski with no clearance gap. For these configurations the wheel was simulated by attaching to the bottom of the ski a block of mahogany the shape and size of the protruding portion of a wheel.

One arrangement represented a wheel mounted at the side of the ski and was made by attaching a mahogany disc to the side of the ski.

The effect of a concentric gap between the wheel and the ski was briefly investigated by mounting a disc so as to protrude through a hole in the ski. The gap between the wheel and the ski was approximately one-sixteenth of an inch. This combination was tested with the wheel both free to rotate and fixed. In addition, the effect of a fairing in front of the freely rotating wheel was investigated.

The model was towed with freedom only in draft, the desired load being set by counterbalancing. The model was attached to the carriage by means of a towing staff which was free to move vertically in a system of guide rollers. The horizontal force applied by the model to the system of rollers (resistance) was measured by a spring and strain-gage arrangement. Trimming moment was measured by a strain-gage-equipped dynamometer located at the bottom of the staff. Wetted length was read visually from a scale on the model while the model was being towed and is the distance from the trailing edge of the model to the intersection of the solid-water boundary with the chine.

A wind screen was mounted on the carriage just forward of the model. With this towing arrangement all force and moment tares were determined to be negligible within the range of the tests.

PROCEDURE

The tests were made by towing the models at various fixed speeds, loads, and trims. Trim is the angle between the bottom of the model and the horizontal. The minimum speed at each load and trim was just above the speed at which the model submerged. The maximum speed at each condition of load and trim was usually high enough so that the protruding portion of the wheel was well clear of the water. The maximum testing speed chosen was 60 feet per second.

The trimming moments presented are referred to the trailing edge of the model, and positive values indicate a tendency for the model to trim up.

RESULTS

The data gathered are presented in figures 2 to 20 as plots of resistance, trimming moment, and wetted length against speed. For reference purposes, the data for the bare ski are given in figure 2. Data on the wheel-ski combinations are shown in figures 3 to 20. Comparisons of the data are given in figures 21 to 31. In order to simplify the comparison plots only selected curves from the data are given but these are believed sufficient to illustrate the effects. In the discussion following only the comparison plots are referred to, the original data of figures 2 to 20 being presented to enable more complete comparisons if they are desirable.

DISCUSSION

General Effect of a Wheel

The general effect of a wheel on the planing characteristics of a ski is illustrated by comparing the data for the bare ski (model 291) and the basic wheel-ski arrangement (model 291A). These data are compared in figure 21.

The planing action of a ski with a protruding wheel can be divided into three phases: The initial, or low-speed phase, the protruding portion of the wheel is well-submerged; an intermediate phase, the protruding portion of the wheel is emerging from the water; and the final, high-speed phase, the wheel is clear of the water and any spray.

In the initial phase the resistance of the combination is greater than that of the bare ski, the penalty being largest at low trims and high speeds. In general, the same is true of the trimming moments and the wetted lengths. With few exceptions, no marked difference in spray pattern was noted between the bare ski and the combination of wheel and ski in this phase of operation.

The early portion of the second phase of operation is characterized by an increase in increments of resistance, trimming moment, and wetted length (figs. 21(b), 21(c), and 21(d)). Transition to the third, or wheel-out-of-water phase varies with the trim. At the lowest trim, 2°, the lowest part of the wheel was below the trailing edge of the ski so that the wheel could not clear the water. Consequently, at this trim the resistance penalty due to the wheel increased up to the highest speed tested, except for an unexplained discontinuity. The wetted length decreased up to the speed of the discontinuity and then stayed practically constant with further increase in speed (fig. 21(a)). At a trim of 4° transition to the third phase was accomplished smoothly with the lighter loads and discontinuously at the higher loads, as shown in figure 21(b). In the region of the discontinuity the model could plane either with the wheel in or out of water depending on whether the given load was approached from a lighter or heavier load. At a trim of 6°, transition was accomplished smoothly at all of the loads tested (fig. 21(c)). With trims of 12° and 16° the transition is marked, at the heavier loads, by two peaks as shown in figures 21(d) and 21(e). It will be noted that, with a trim of 16° and a load of 14 pounds, the resistance of the combination is less than that of the ski alone for a narrow range of speed. This effect could possibly be due to impingement of forward moving spray on the rear of the wheel. In the intermediate phase a larger amount of spray was thrown out from the model with the wheel than was thrown out from the bare ski.

It was believed possible that one source of the resistance penalty with the wheel was an increase in skin friction caused by the boundary layer being changed from laminar to turbulent. In an effort to check the existence of this change, a strip of 150-grit abrasive paper was glued on the bottom of the model. This strip, $\frac{1}{2}$-inch in fore-and-aft dimension, extended from chine to chine and was located immediately forward of the protruding portion of the wheel. The total thickness of the strip was 0.017 inch which is believed to be greater than the thickness of the laminar boundary layer. No measurable increase in resistance resulted from the strip either with or without the wheel installed. This result indicates that the effect of the wheel is much greater than that due to any turbulence-generating effect.

In the final wheel-clear phase of operation the wheel presumably could only affect the aerodynamic forces and, since a wind screen was used, the test data show no effect of the wheel.

Effect of Wheel Shape and Size

Diameter of wheel.- The effect of increasing the diameter of the wheel from 25 to 50 percent of the length of the ski with a constant protrusion is indicated in figure 22 for a trim of 6°. The data show that the smallest wheel caused the largest increase in resistance, although the difference is small. These data indicate that the shape or "fairness" of the protruding portion of the wheel may be more important than the volume, surface area, or ski planing area that is blocked off. Only minor changes in trimming moment and wetted length occurred as a result of changing the wheel diameter.

Width of wheel.- The effect of increasing the width of the wheel from 35 to 100 percent of the beam of the ski is indicated in figure 23. The much greater resistance with the wide wheel is evident. In addition, the resistance hump occupies a considerably larger speed range for the model with the wide wheel and large discontinuities accompany transition.

It is interesting to note that the wide wheel is contributing a substantial amount of lift when submerged as evidenced by the lower wetted length with this wheel than with no wheel. In the intermediate phase, the wide wheel could possibly be contributing a downward force since the wetted length is increased over that for the bare ski. This downward force would then be balanced by an increment of lift from the ski because of the increased wetted length. Since this added increment of lift from the ski is farther forward than the downward force from the wheel, the net result is an increase in bow-up moment as shown.

Cross section of wheel.- A comparison of the characteristics of skis with wheels of square and rounded cross section is given in figure 24. Rounding the cross section of the wheel considerably reduced the peak resistance. The reduction in resistance is believed to be due to the lower exposed volume, decreased surface area, and to the more fair lines of the wheel with the rounded cross section. The effects of the change in cross section on the trimming moment and wetted length were not significant.

Effect of Wheel-Ski Arrangement

Fore-and-aft location of wheel.- The effect of varying the fore-and-aft location of the wheel is illustrated in figure 25. The wheel center location varied from 20 percent to 93.5 percent of the ski length aft of the leading edge. Successive locations of 20, 40, and 60 percent resulted in successively higher values of maximum resistance and in resistance humps covering a wider speed range. This result is probably due to the increasing speed of emergence as the wheel was moved aft.

With the center of the wheel at 80 percent of the length of the ski, the wheel did not emerge up to the highest speed tested. Transition, however, could probably have taken place at a sufficiently high speed since an unobstructed planing area aft of the wheel existed except at very low trims. With the most aft wheel location tested (center of wheel at 93.5 percent of length of ski) a complete emergence of the wheel was not possible and the resistance is also shown to be increasing at the highest test speed. A discontinuity in the curves for this wheel location was found but its causes are unknown.

Except for the most aft wheel location, changing the fore-and-aft location of the wheel had no significant effect on trimming moment or wetted length. With the wheel at the trailing edge of the ski, the wetted length and trimming moment at low speeds were considerably increased over that for the bare ski. This increase in wetted length indicates that the wheel may possibly contribute a downward force which is balanced by an increment of planing lift. Since this increment of lift and wetted area is forward of the wheel, the net result is an increase in bow-up moment. The addition of a wheel to the trailing edge of the ski increases the minimum planing speed for a given load and trim. At speeds higher than that at which the discontinuities occur, the wetted length and trimming moment approach constant values.

Lateral location of wheel.- The effect of mounting a wheel on the side of the ski was briefly investigated. The resistance peak which occurred near the emergence of the wheel on the center line did not appear with the wheel on the side (fig. 26). The configuration with the wheel on the side, however, had a much higher resistance than the center-wheel model when the wheels were submerged. This effect was apparently due to the large amount of water climbing up the fore-and-aft surfaces of the wheel. In an attempt to eliminate this undesirable flow condition and lower the resistance, small breaker strips were mounted on the tread face of the wheel. The breaker strips were not very effective in reducing resistance but the wetted length and trimming moment indicate that they produced some lift at low speed. Data for models $291A_3$ and $291A_4$ are not included in figure 26 as they had approximately the same effect as the strip arrangement of model $291A_5$.

Gap between wheel and ski.- The effect of a small clearance gap between a wheel and the ski is shown in figure 27. The resistance was greater with a gap than without except during the final part of the intermediate phase. A rather large amount of water flowed through the gap during both submerged operation and the early portion of emergence. A heavy jet of water emerged from the rear of the gap and formed a fountain. The water emerging from the front and sides flowed around the wheel and streamed aft along the deck. The increased resistance was probably due to both the flow of water through the gap and the flow of water over the upper portion of the wheel and deck of the ski. The gap increased the wetted length and trimming moment at low speeds.

Rotation of wheel.- The effect of allowing the wheel freedom in rotation is indicated in figure 28. The difference in resistance, trimming moment, and wetted length between the rotating and the fixed wheel was insignificant and was in the order of magnitude of the accuracy in the measurements. When the protruding portion of the wheel was submerged the wheel rotated in the same direction as if it were rolling along the ground. When the wheel was emerging the speed of rotation decreased, and with a slight emergence the wheel rotated slowly backwards. This backward rotation was probably due to spray impinging on the rear of the protruding portion of the wheel.

Protrusion.- The effect of protrusion of the wheel is indicated in figure 29 for a fixed wheel with no gap and in figure 30 for a freely rotating wheel. It is apparent that, with a fixed wheel and a sealed gap, increasing the wheel protrusion markedly increased the resistance. With the largest protrusion, transition was not completed at a trim of 6° with a load of 10 pounds. Under these conditions, the wetted length approached a constant value and the trimming moment increased as the speed increased. At lighter loads and trims of 4° and 6°, however, transition was effected although accompanied by large discontinuities (figs. 16(a) and 16(b)). At a trim of 12° transition was accomplished smoothly, as shown in figure 16(c). With a freely rotating wheel an increase in protrusion also increased the resistance. Apparently, however, this effect on the resistance was less with a freely rotating wheel than with a fixed sealed wheel. In addition, an increase in protrusion with the freely rotating wheel increased the trimming moment although the changes in wetted length were small.

Fairing forward of wheel.- The effect of a fairing forward of the wheel is shown in figure 31. The fairing had a favorable effect on the resistance and reduced it considerably. This result tends to bear out the belief that the "fairness" of a protuberance on a ski may be more important than its size. No significant effect on the trimming moment is evident but the fairing increased the wetted length somewhat.

Possible Methods of Reducing Resistance

The data presented lead to several conclusions on wheel-ski arrangements which result in the minimum resistance penalty due to the wheel. The wheel should be as "fair" as possible, that is, it should be narrow with respect to the beam of the ski and have a rounded tread, a large diameter, and a low protrusion. If practicable, a fairing should be installed, as it would help reduce the resistance. It would be desirable to seal the gap between the wheel and ski during operation on the water.

In addition to these considerations in minimizing resistance, attention should be paid to the fore-and-aft location of the wheel, since the resistance penalty is highest when the wheel is emerging. A wheel near the bow of the ski will emerge at a low speed and therefore eliminate the effect of the wheel over the maximum part of the take-off speed range. At these low emergence speeds, however, the trim probably would be high in order to maintain planing and the resistance of the ski alone will be high. In this case, although the increment of resistance due to the wheel is small at a high trim, it may be unacceptable if the thrust margin is small. A more aft location of the wheel might relieve such a situation because the wheel would emerge at a higher speed where the ski would be operating at a trim nearer its minimum resistance. A wheel near the trailing edge of the ski might be acceptable if, at take-off speed, the wheel was well-submerged. In this case the wheel would emerge as the airplane was pulled off by the pilot and the high resistance peak would occur as a transient condition on a lightly loaded ski.

CONCLUSIONS

The results of an investigation of the planing characteristics of various combinations of a wheel and a hydro-ski led to the following conclusions:

1. In general, a combination of a wheel and a hydro-ski had a higher resistance than the bare hydro-ski, unless the wheel was clear of the water. The resistance penalty due to an inserted wheel was lowest when the ski was wetted well forward of the wheel and highest when the wheel was near emergence.

2. The resistance penalty due to a wheel was found to be considerably influenced by the "fairness" of the protruding portion of the wheel. An increase in wheel diameter with a constant protrusion resulted in a lowered resistance. Also a fairing mounted on the bottom of the ski just forward of the wheel lowered the resistance. Changing the shape of the cross section of the wheel from a flat tread to a circular section considerably reduced the resistance.

3. An increase in width or protrusion of the wheel resulted in a marked increase in resistance.

4. When the wheel is below the trailing edge of the ski it is not possible for the wheel to emerge and the resistance will rise continuously as the speed is increased.

5. Moving the wheel aft on the ski resulted in successively higher peak values of resistance at wheel emergence, when emergence was possible.

6. A wheel on the side of the ski had a lower resistance near emergence but a higher submerged resistance than a similar wheel inserted through the center of the ski.

7. A small gap between the wheel and the ski increased both the submerged and emergence resistance.

8. Allowing the wheel freedom to rotate had little effect on the resistance.

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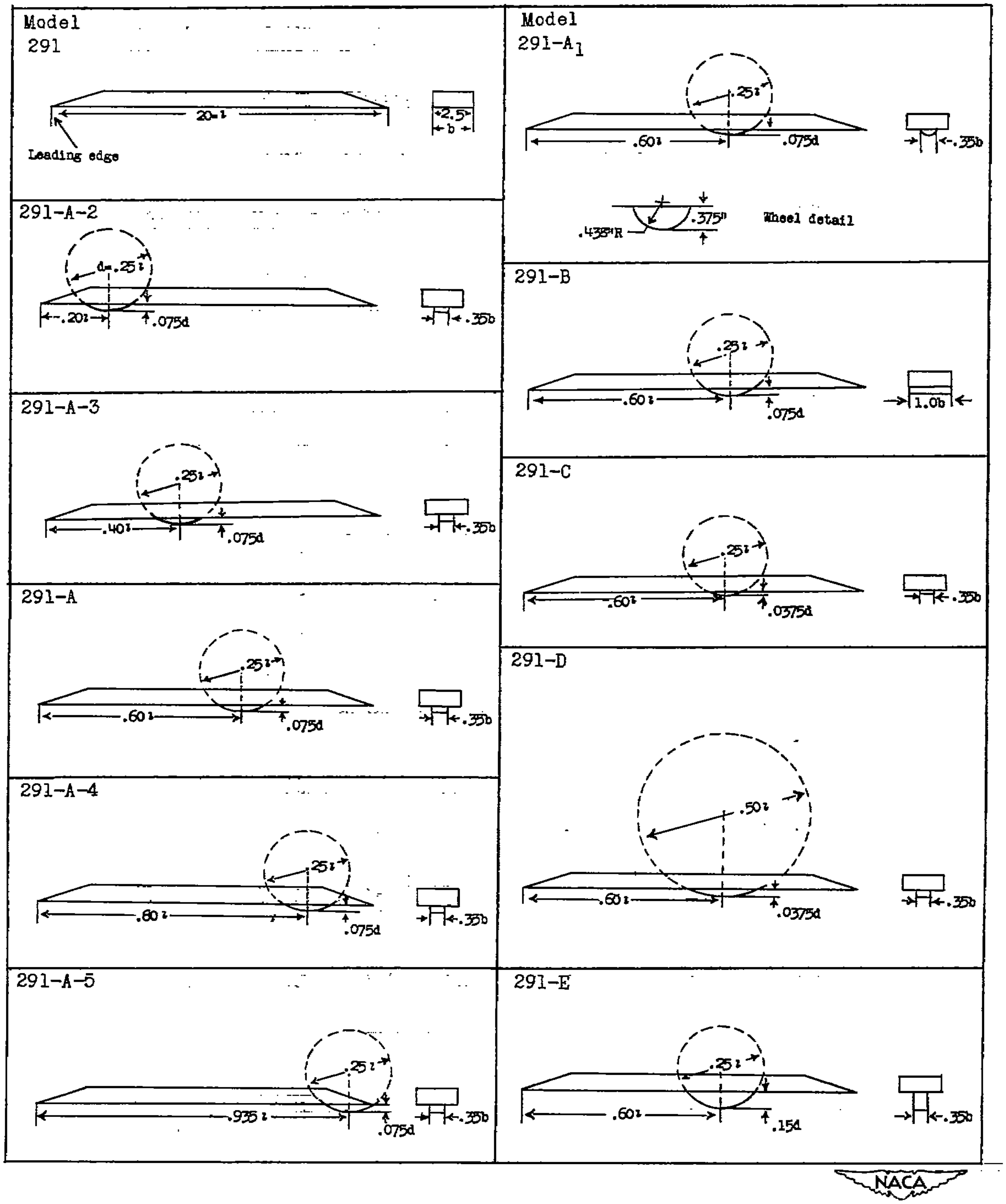
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCE

1. Walden, Jack R.: Universal Landing Gear for SNJ Aircraft. Rep. No. N-118 (Contract NOa(s) 11048, Bur. Aero.), All American Airways, Inc., Eng. & Res. Div., Sept. 25, 1950.



(a) Sealed wheels.

Figure 1.- Dimensions of models tested.

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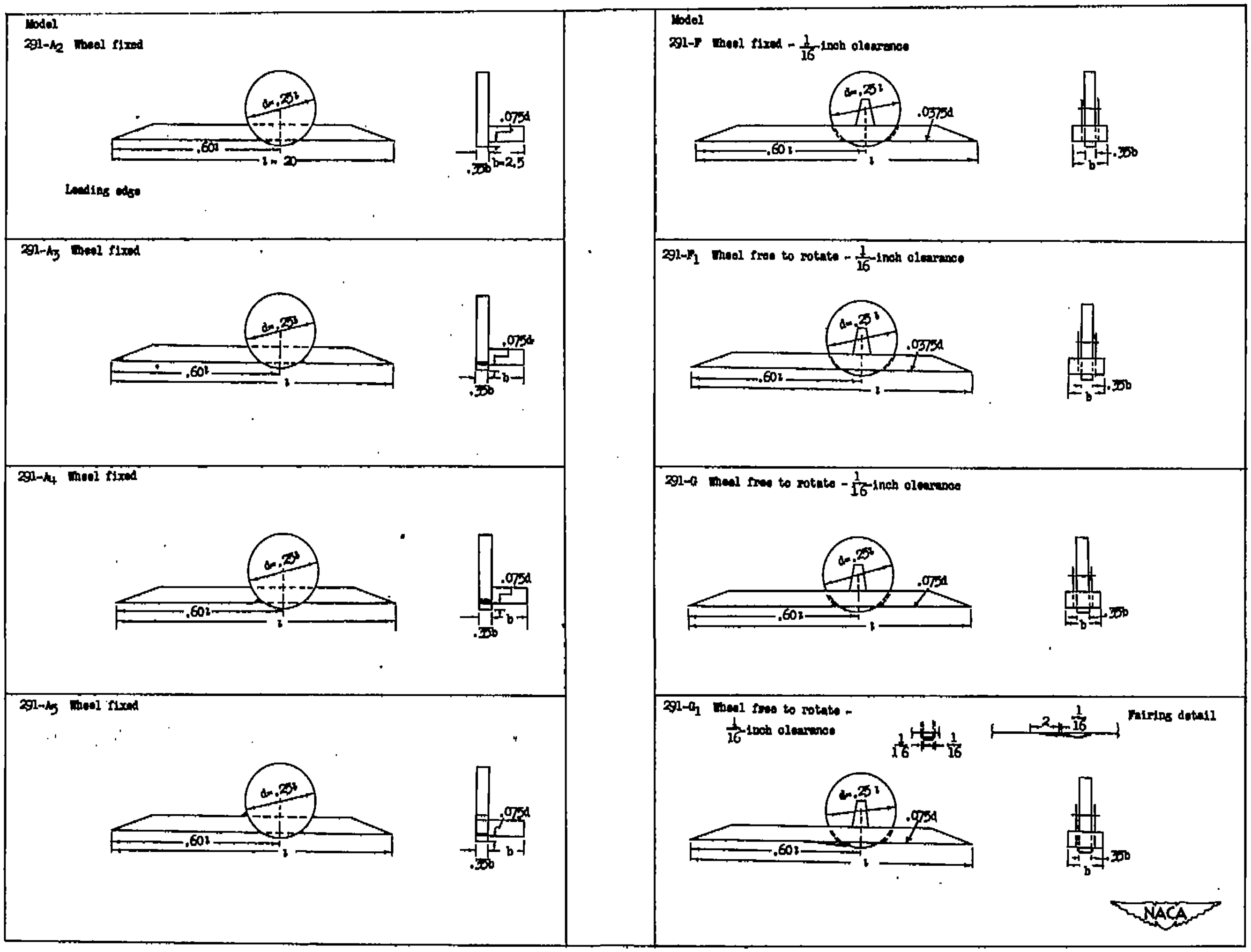
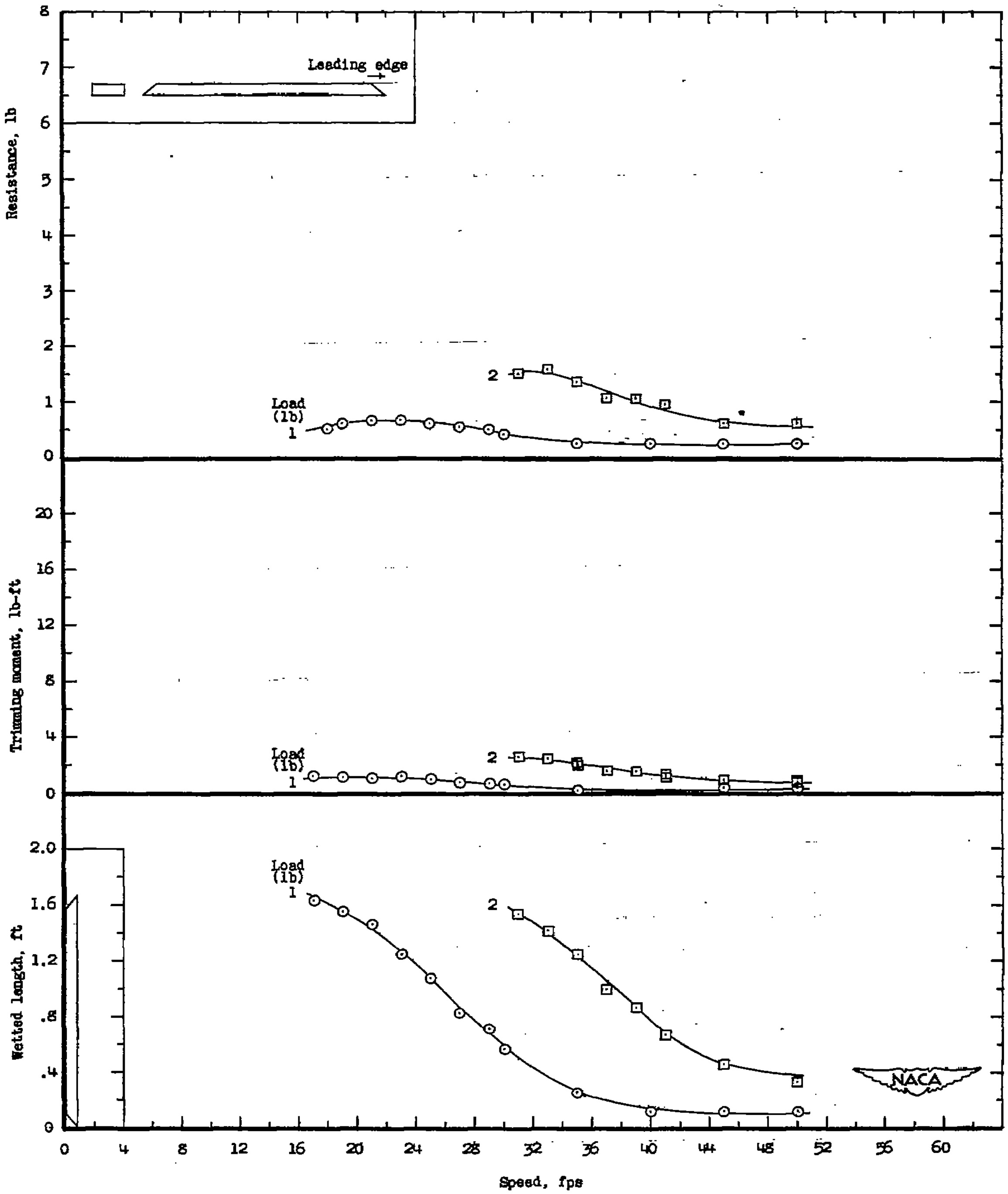


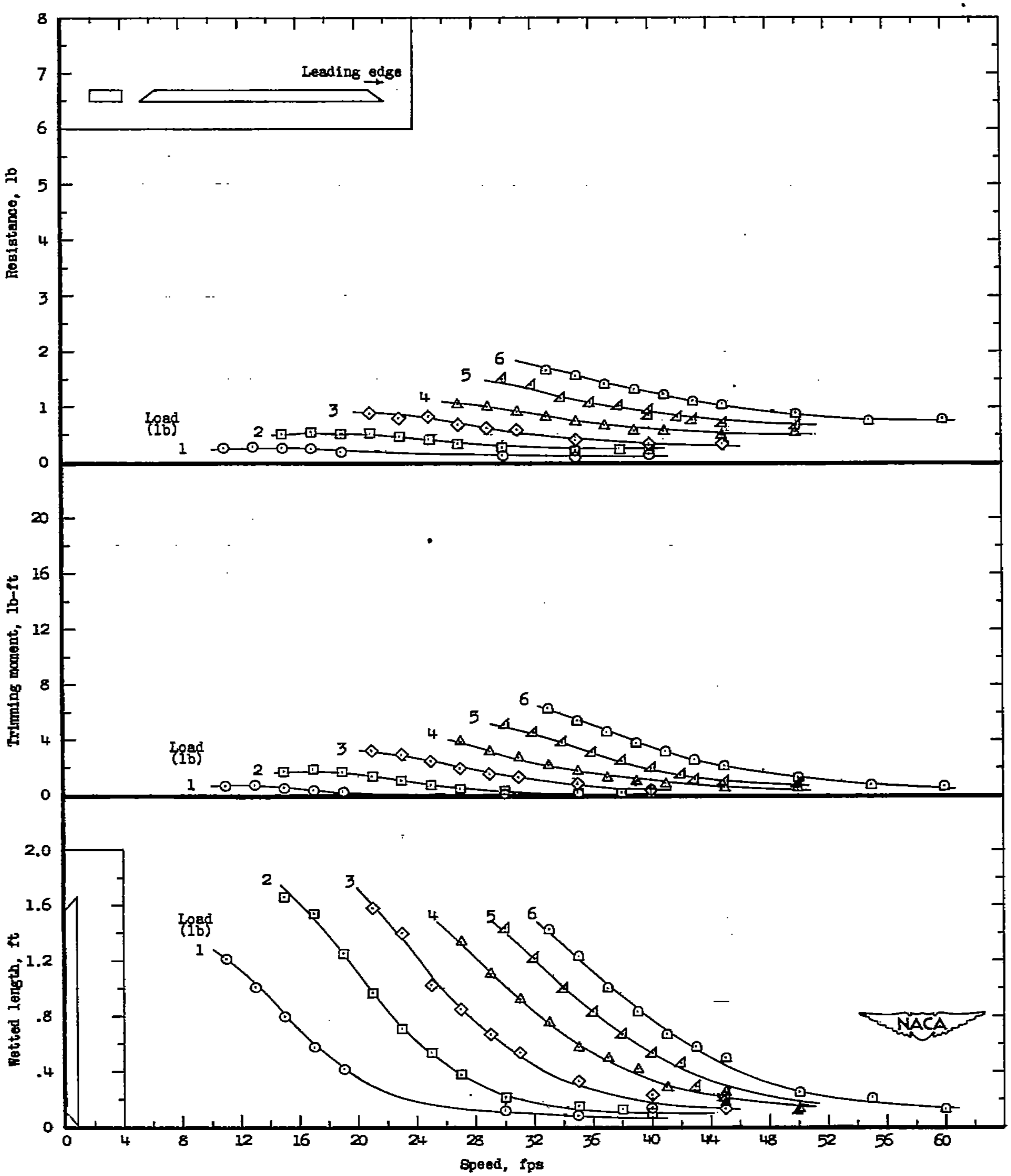
(b) Unsealed wheels.

Figure 1.- Concluded.



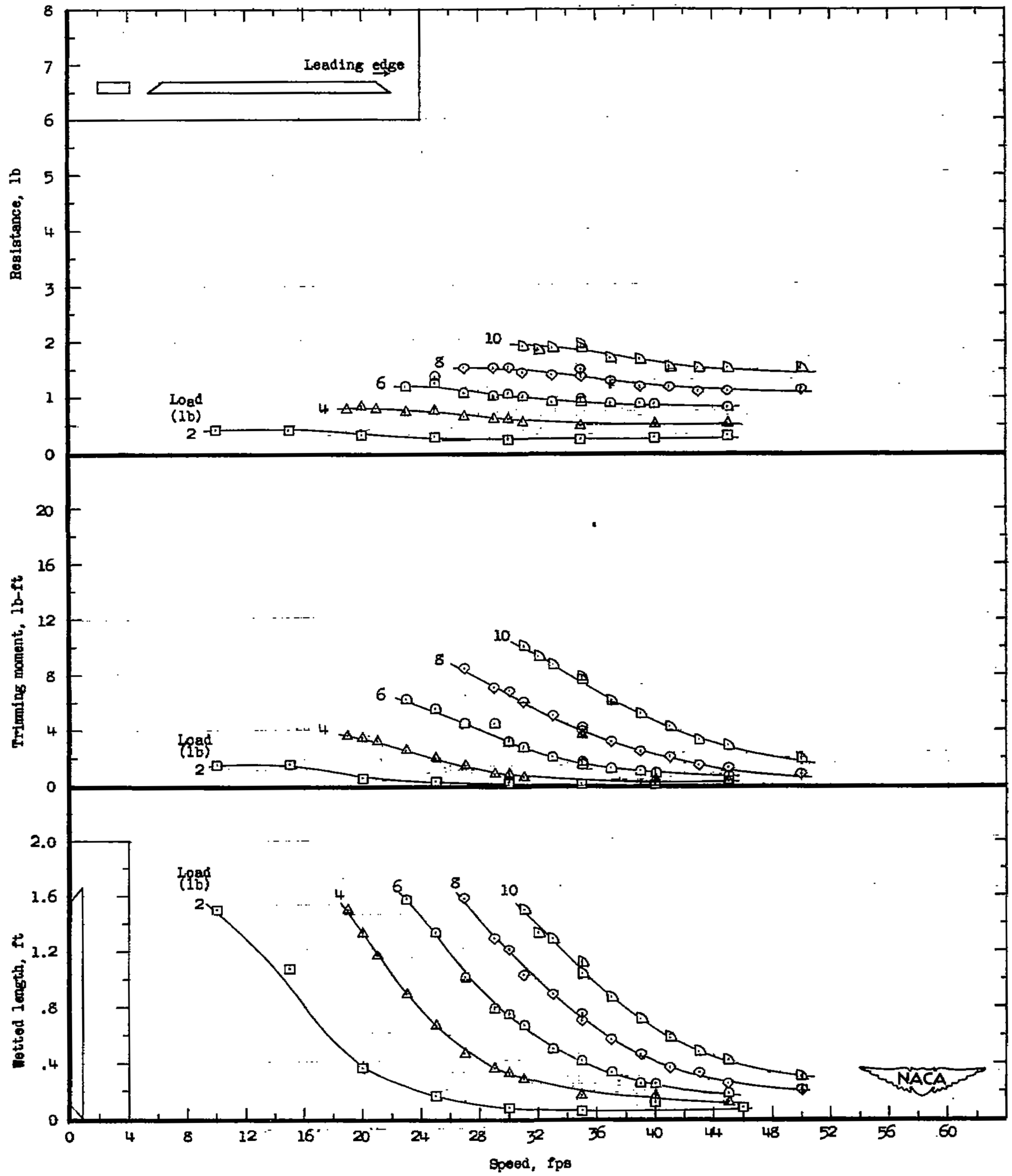
(a) Trim, 2°.

Figure 2.- Model 291. Dead rise, 0°. No wheel.



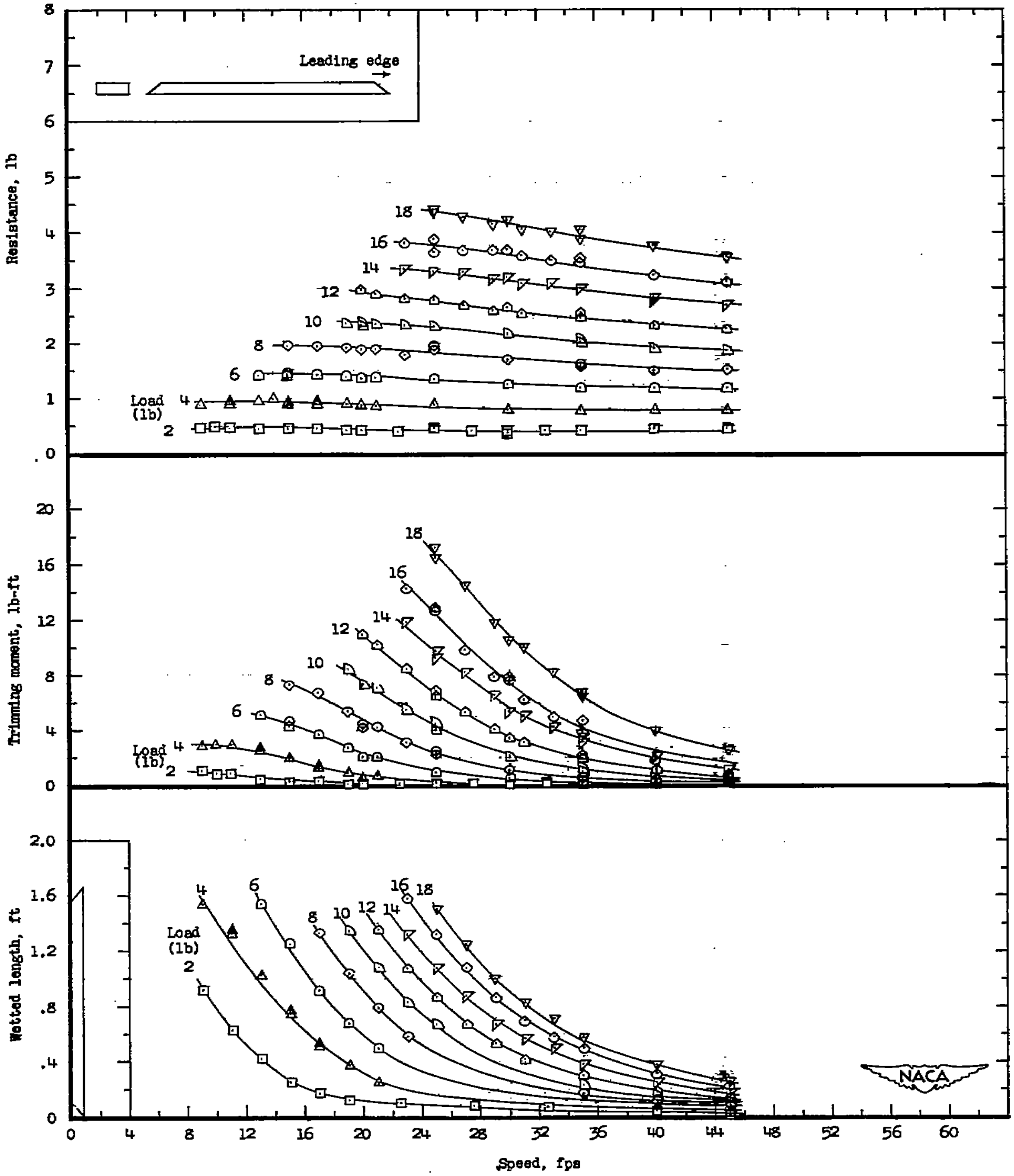
(b) Trim, 4°.

Figure 2.- Continued.



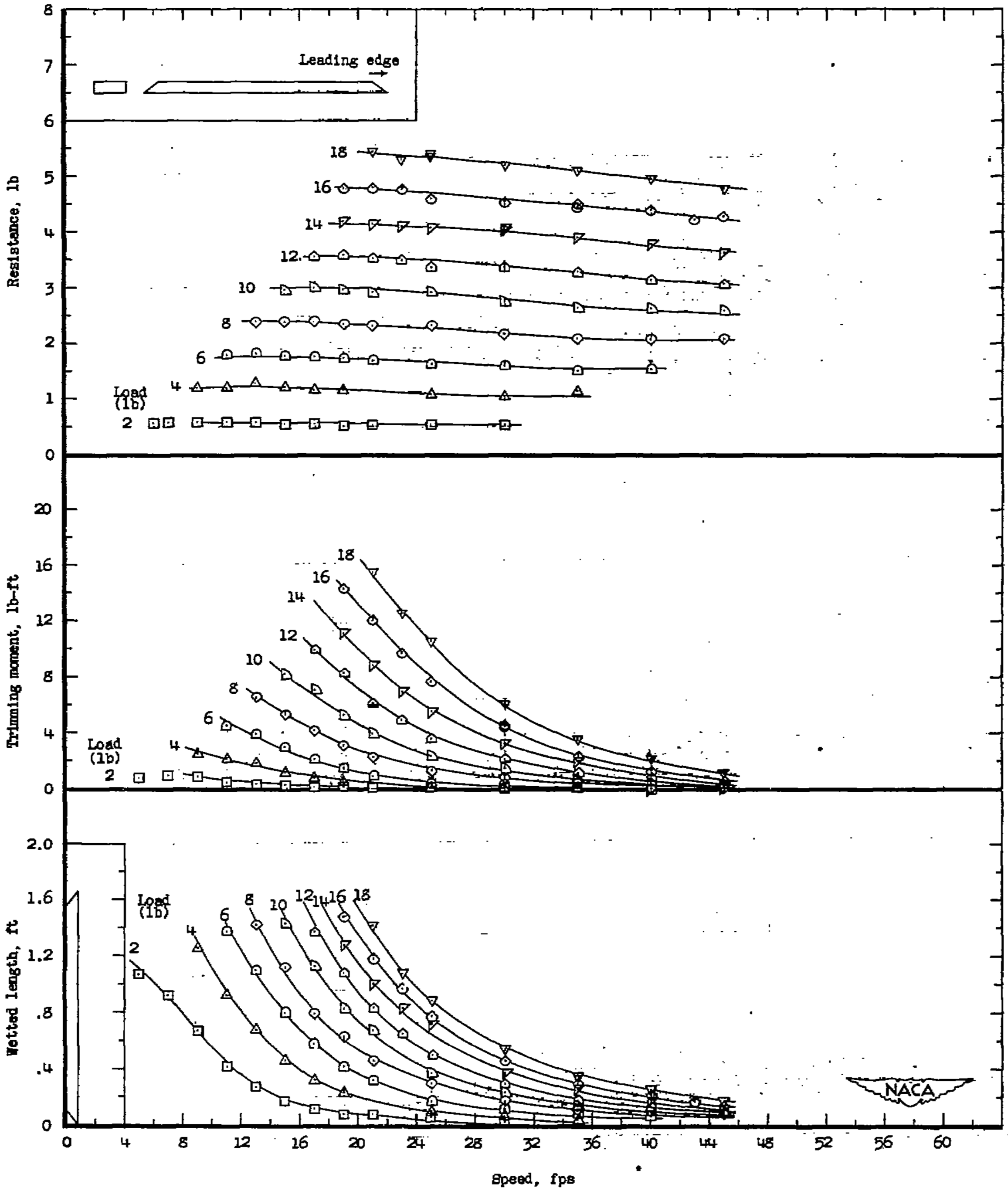
(c) Trim, 6°.

Figure 2.- Continued.



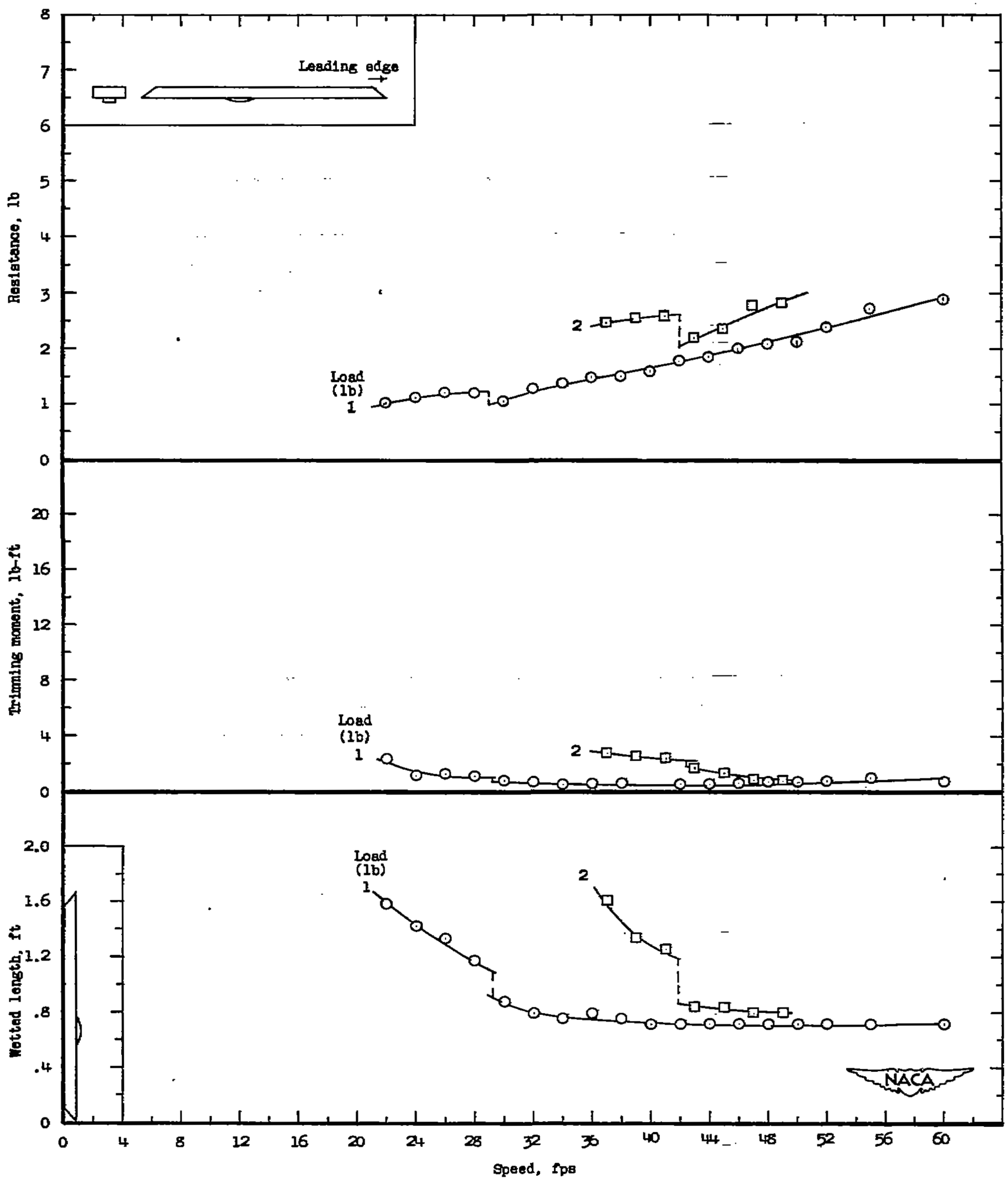
(d) Trim, 12°.

Figure 2.- Continued.



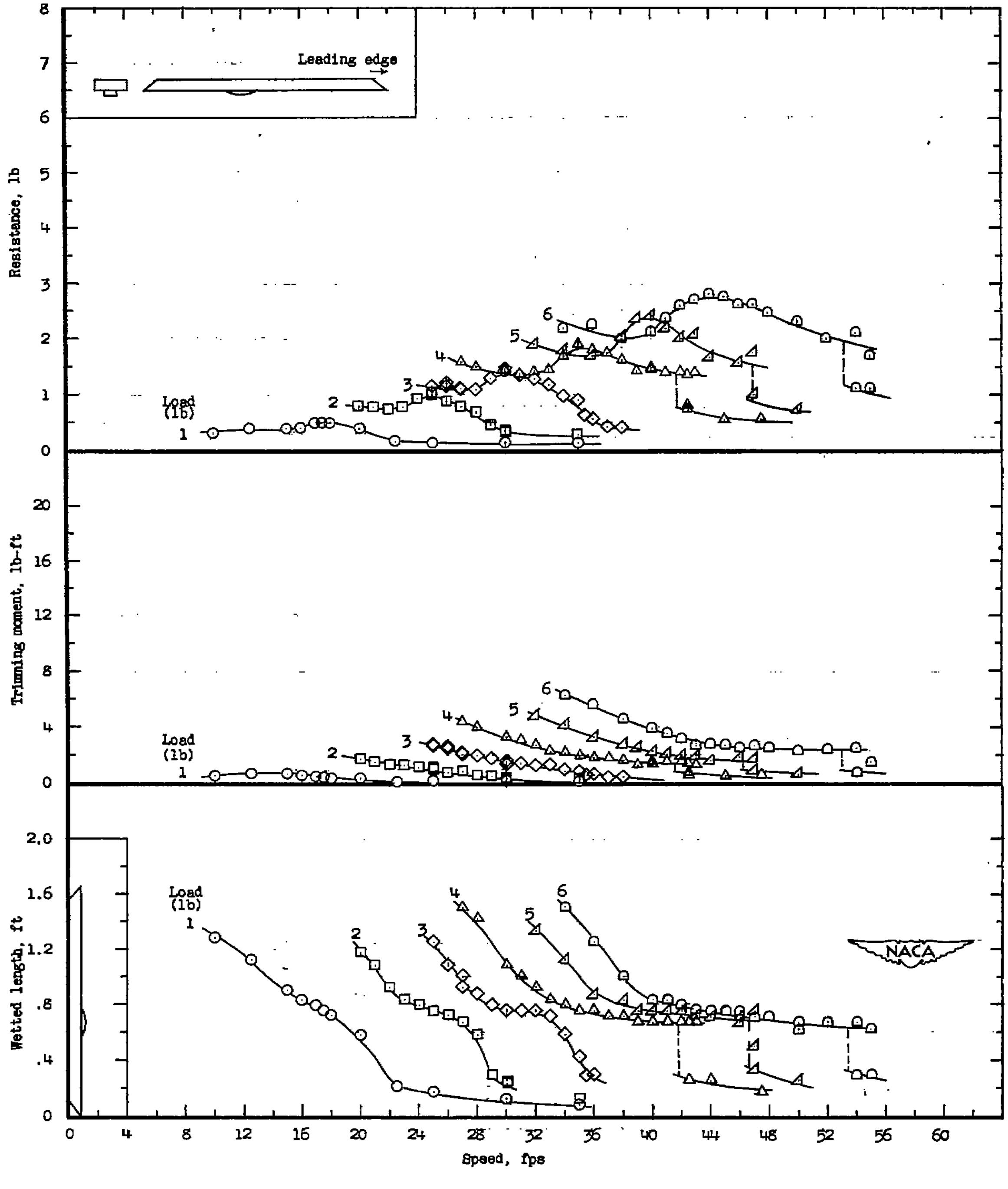
(e) Trim, 16°.

Figure 2.- Concluded.



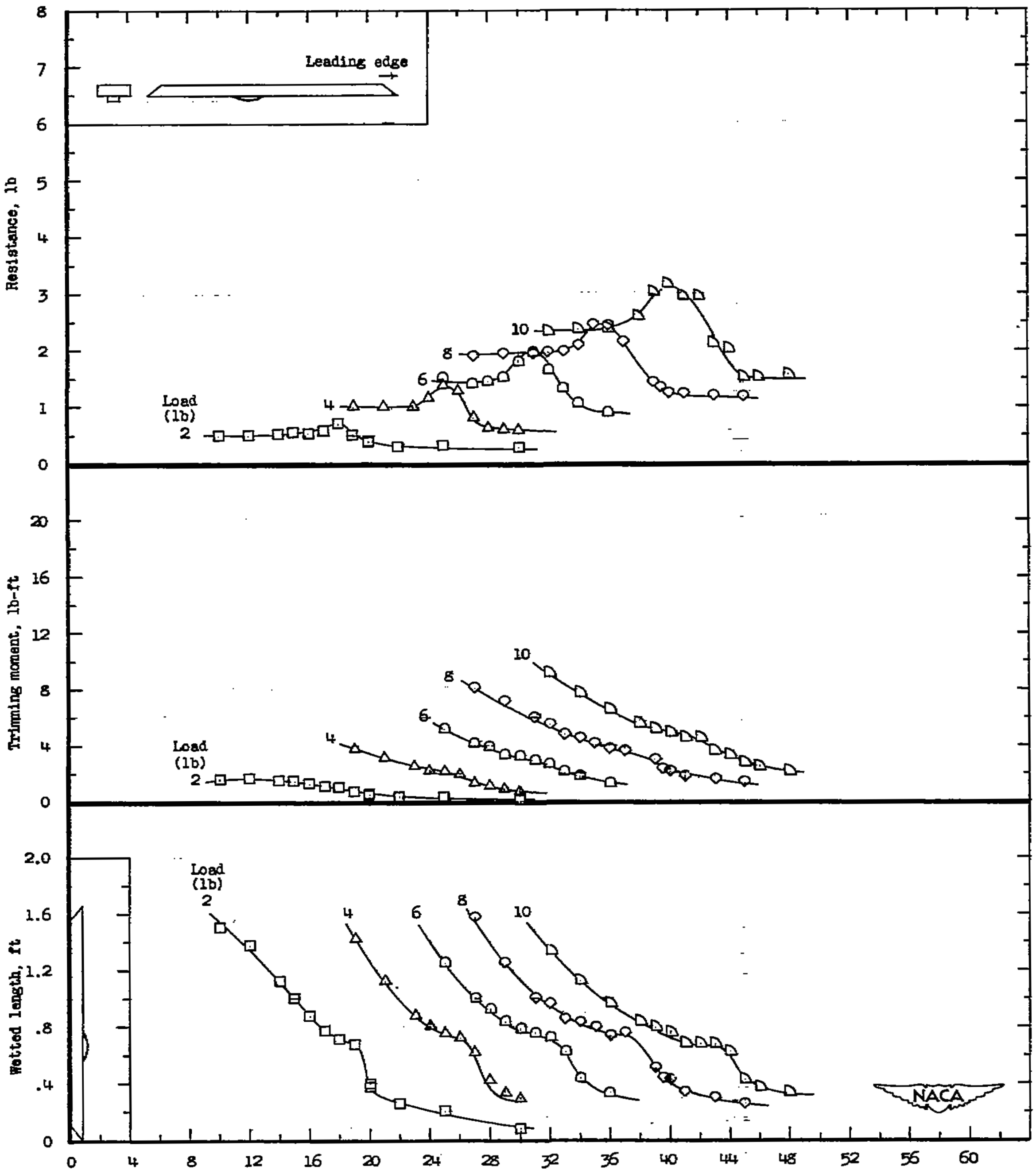
(a) Trim, 2°.

Figure 3.- Model 291A. Dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 60 percent of length of ski.



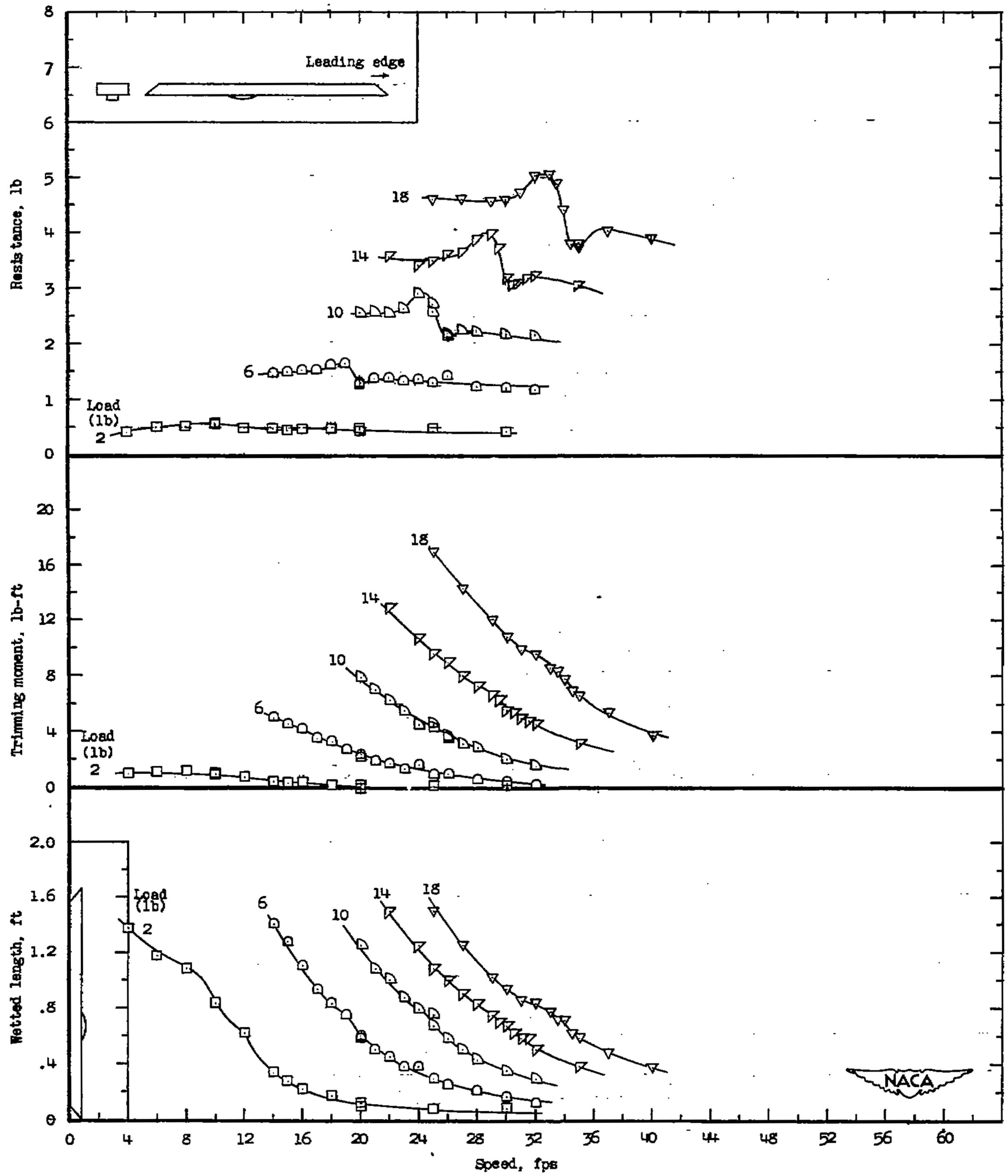
(b) Trim, 4°.

Figure 3.- Continued.



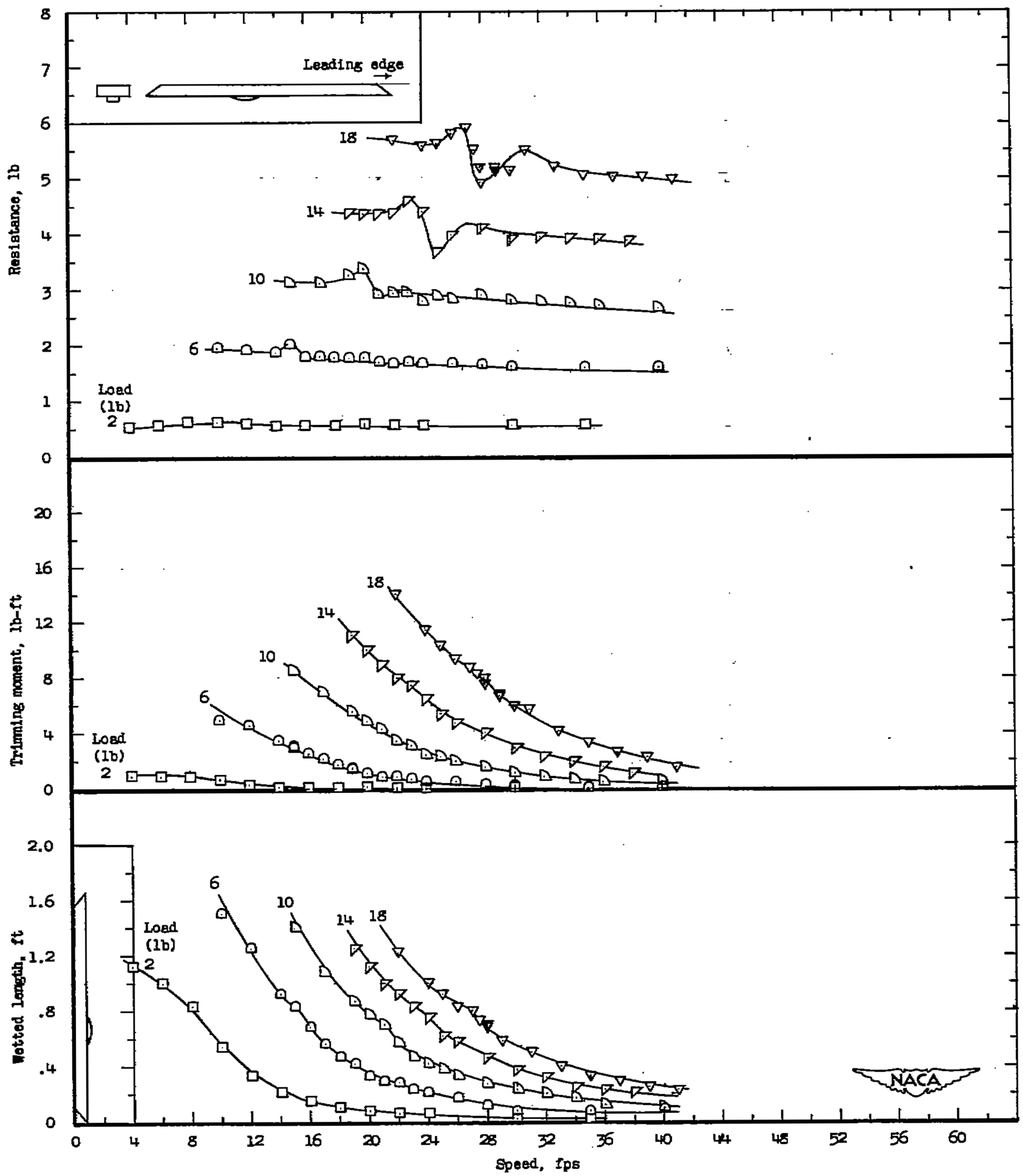
(c) Trim, 6°.

Figure 3.- Continued.



(d) Trim, 12°.

Figure 3.- Continued.



(e) Trim, 16°.

Figure 3.- Concluded.

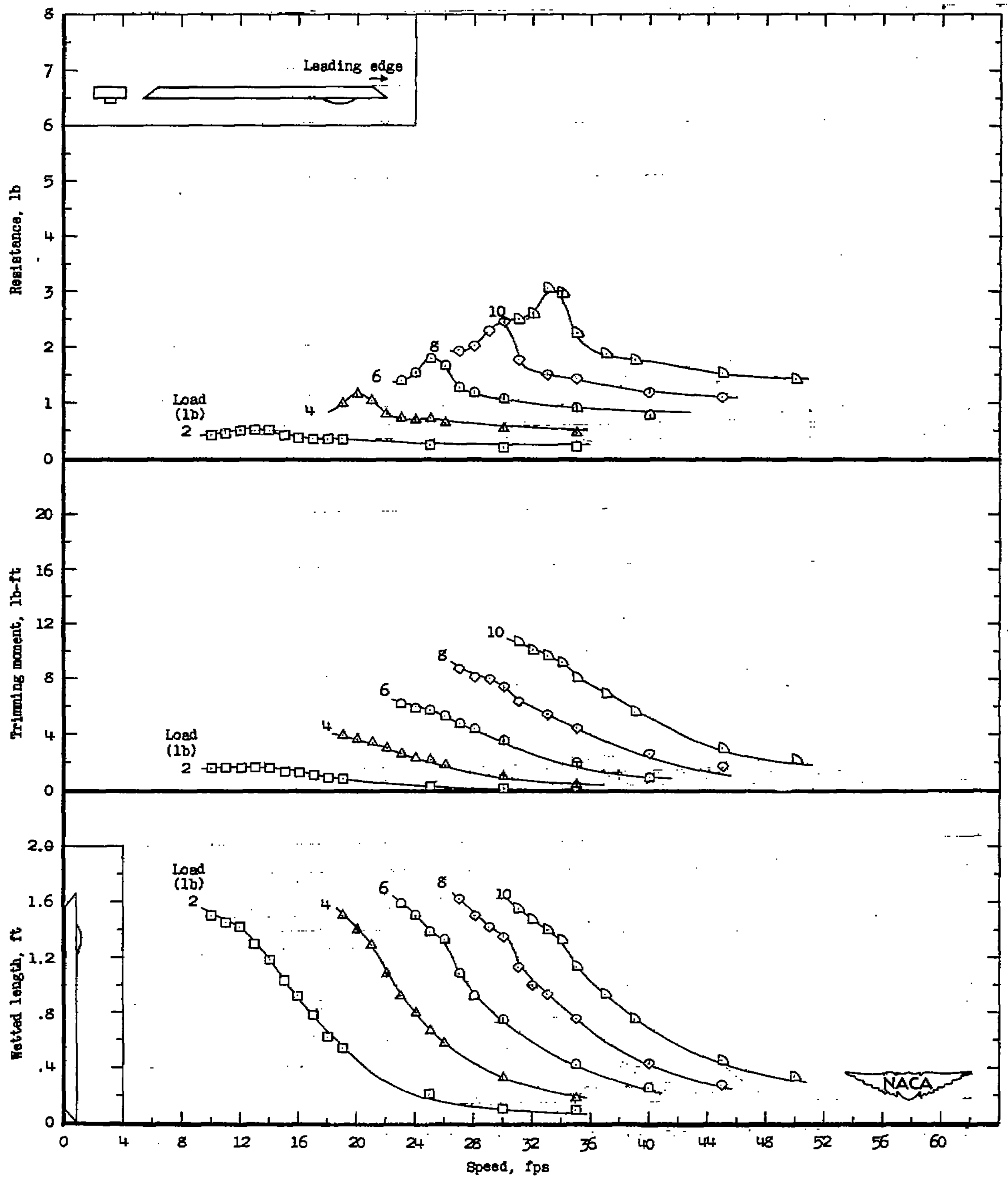


Figure 4.- Model 291A-2; trim, 6°; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 20 percent of length of ski.

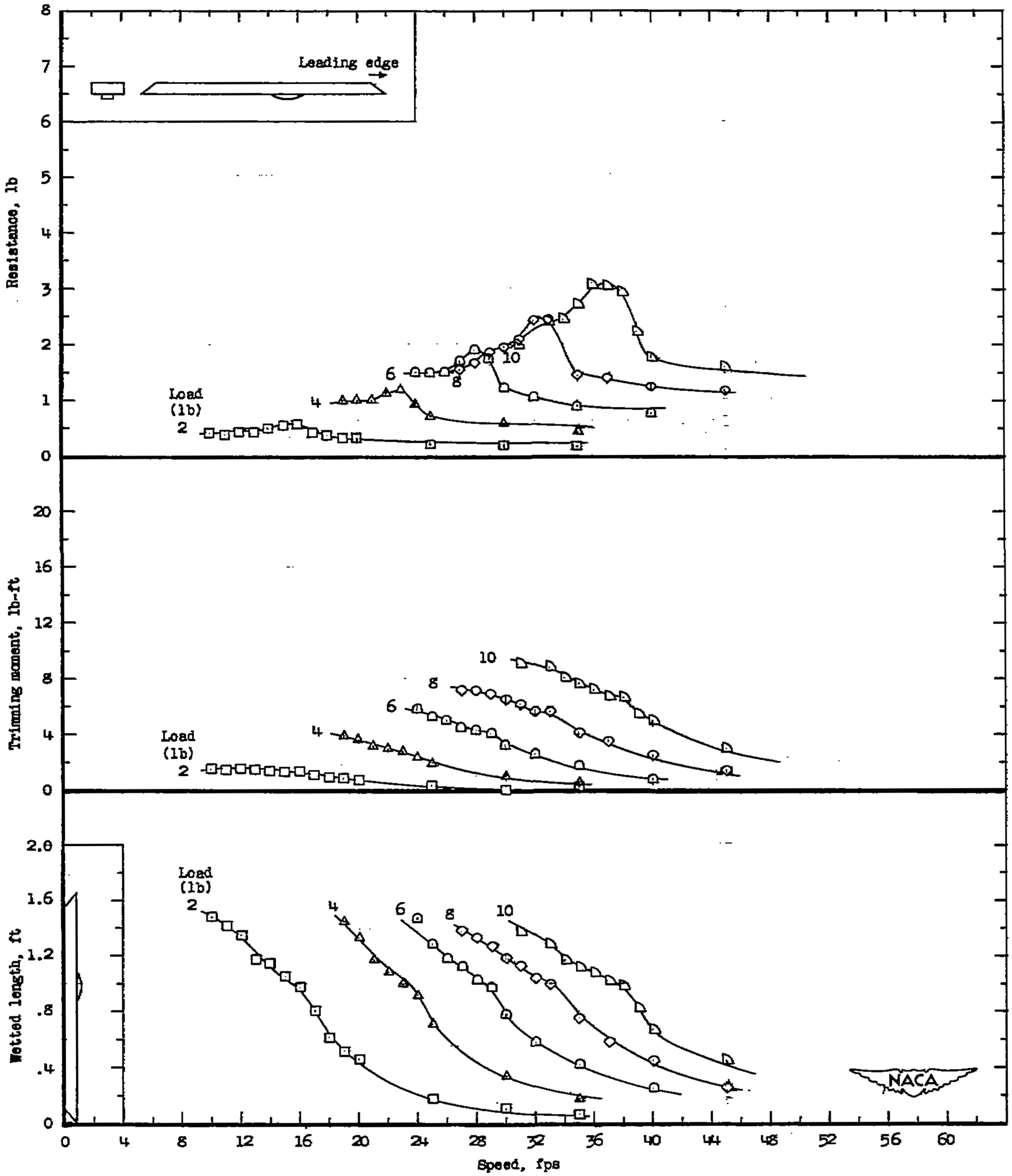


Figure 5.- Model 291A-3; trim, 6°; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 40 percent of length of ski.

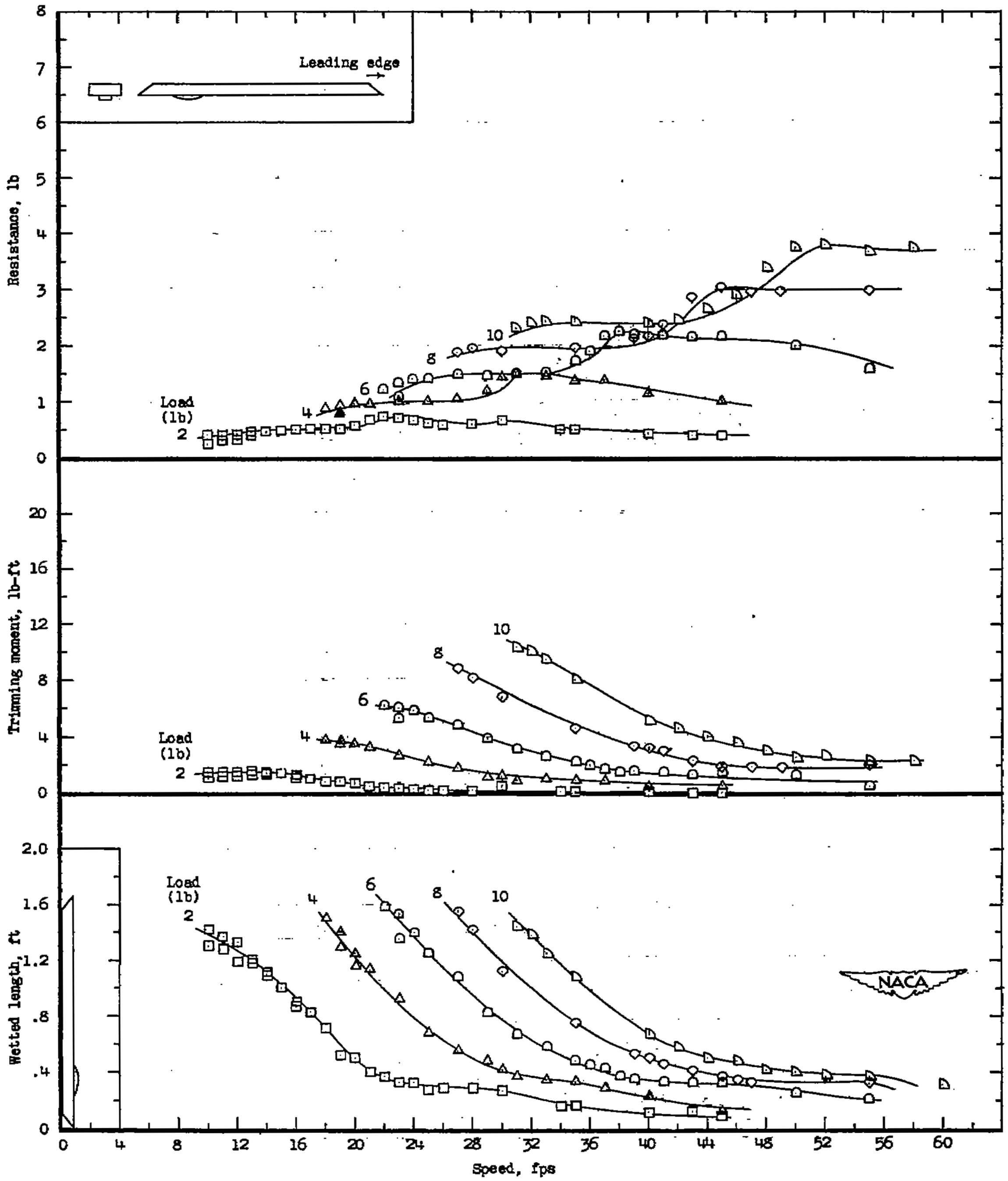


Figure 6.- Model 291A-4; trim, 6°; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 80 percent of length of ski.

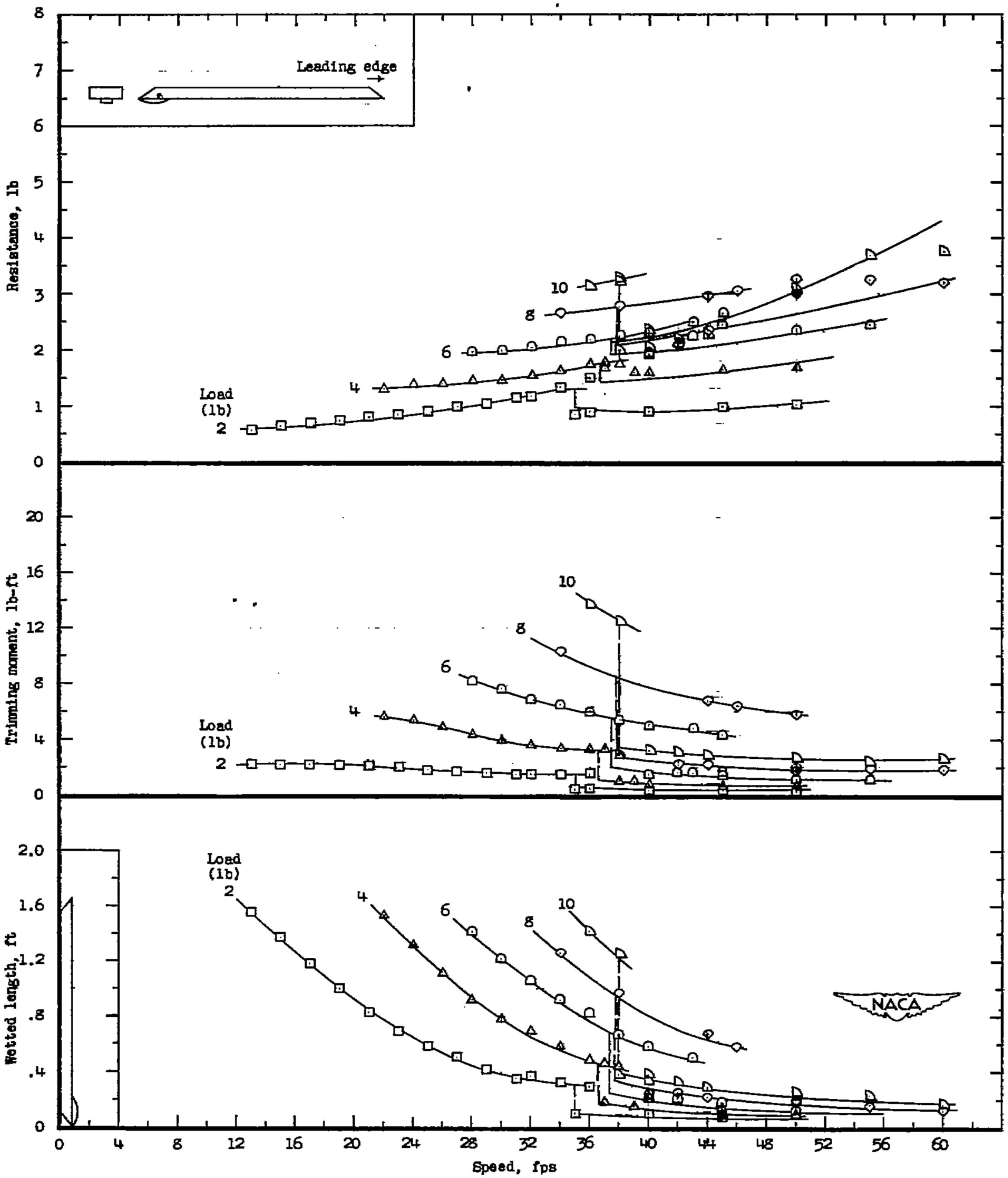
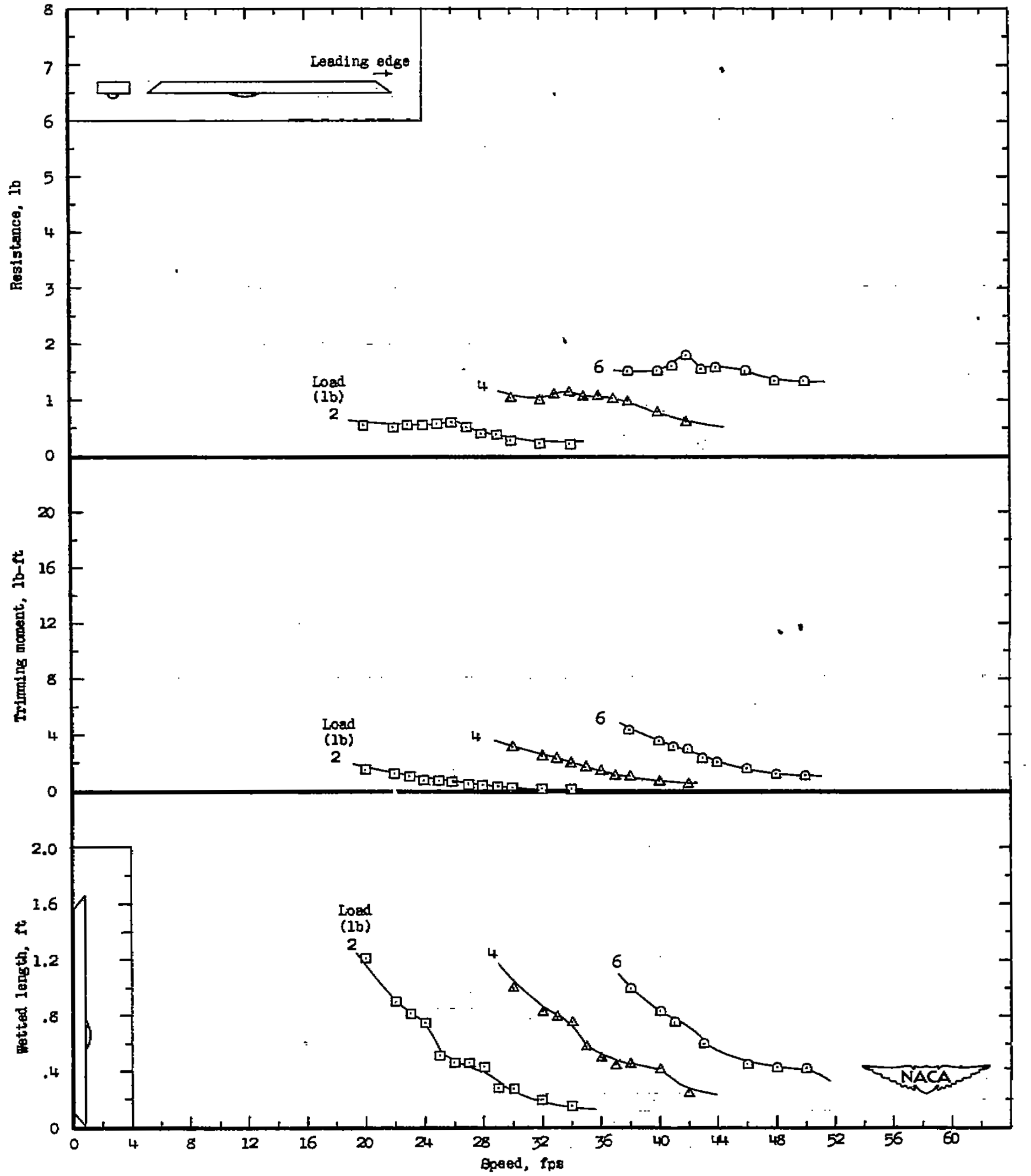
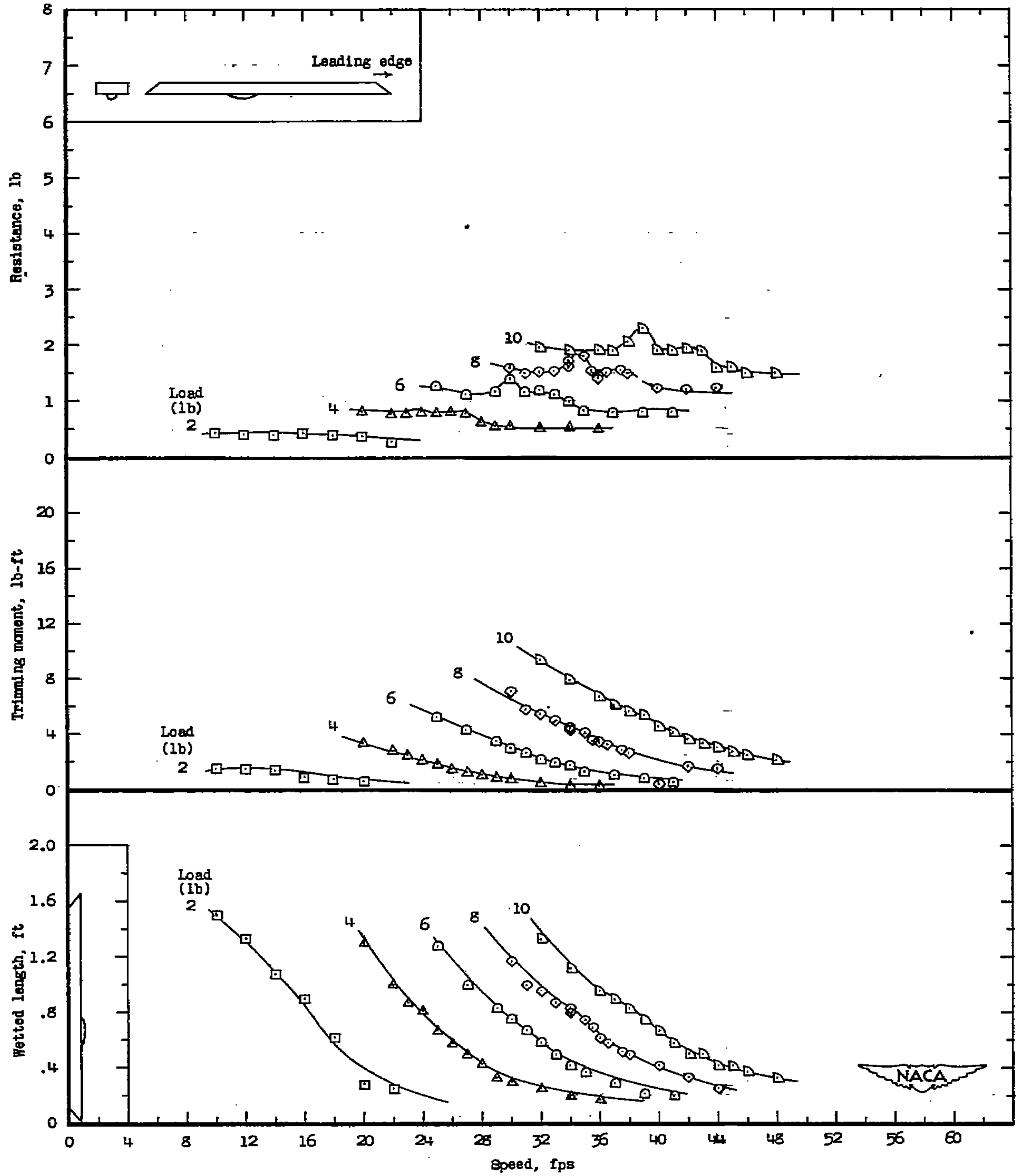


Figure 7.- Model 291A-5; trim, 6°; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 93.5 percent of length of ski.



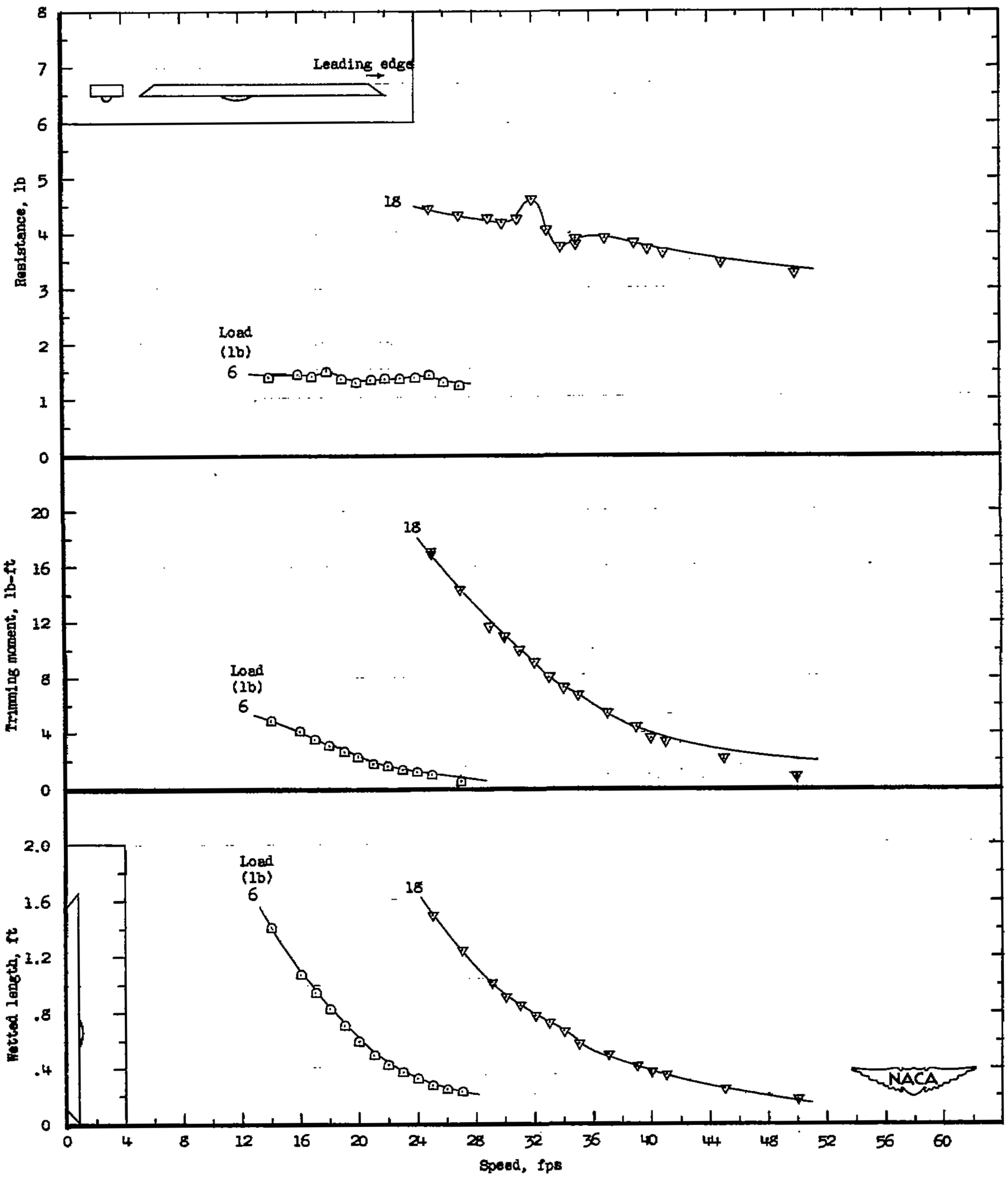
(a) Trim, 4°.

Figure 8.- Model 291A$_1$; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 60 percent of length of ski. Rounded wheel cross section.



(b) Trim, 6°.

Figure 8.- Continued.



(c) Trim, 12°.

Figure 8.- Concluded.

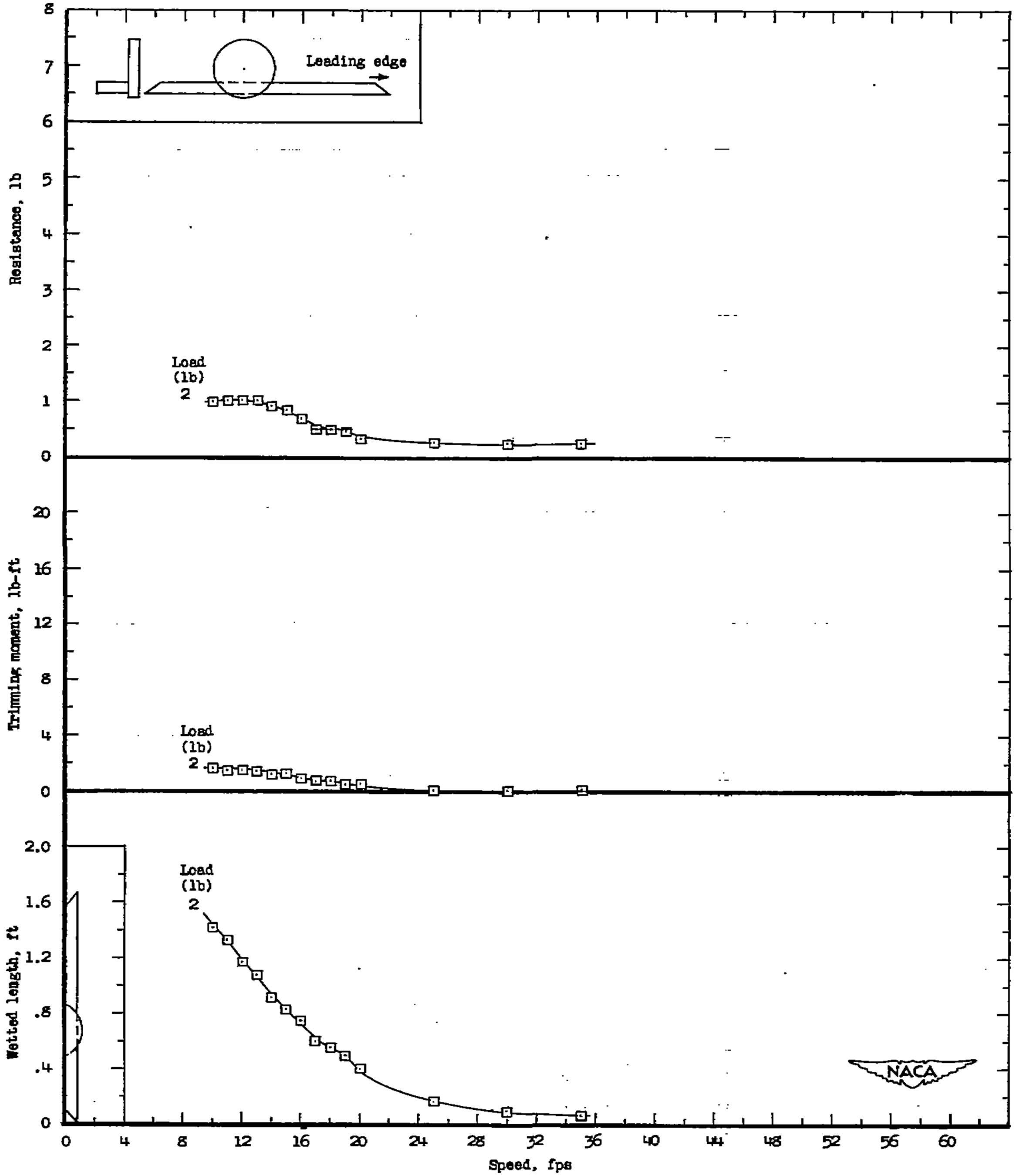


Figure 9.- Model $291A_2$; trim, 6°; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of ski; center of wheel at 60 percent of length of ski; wheel on side of ski.

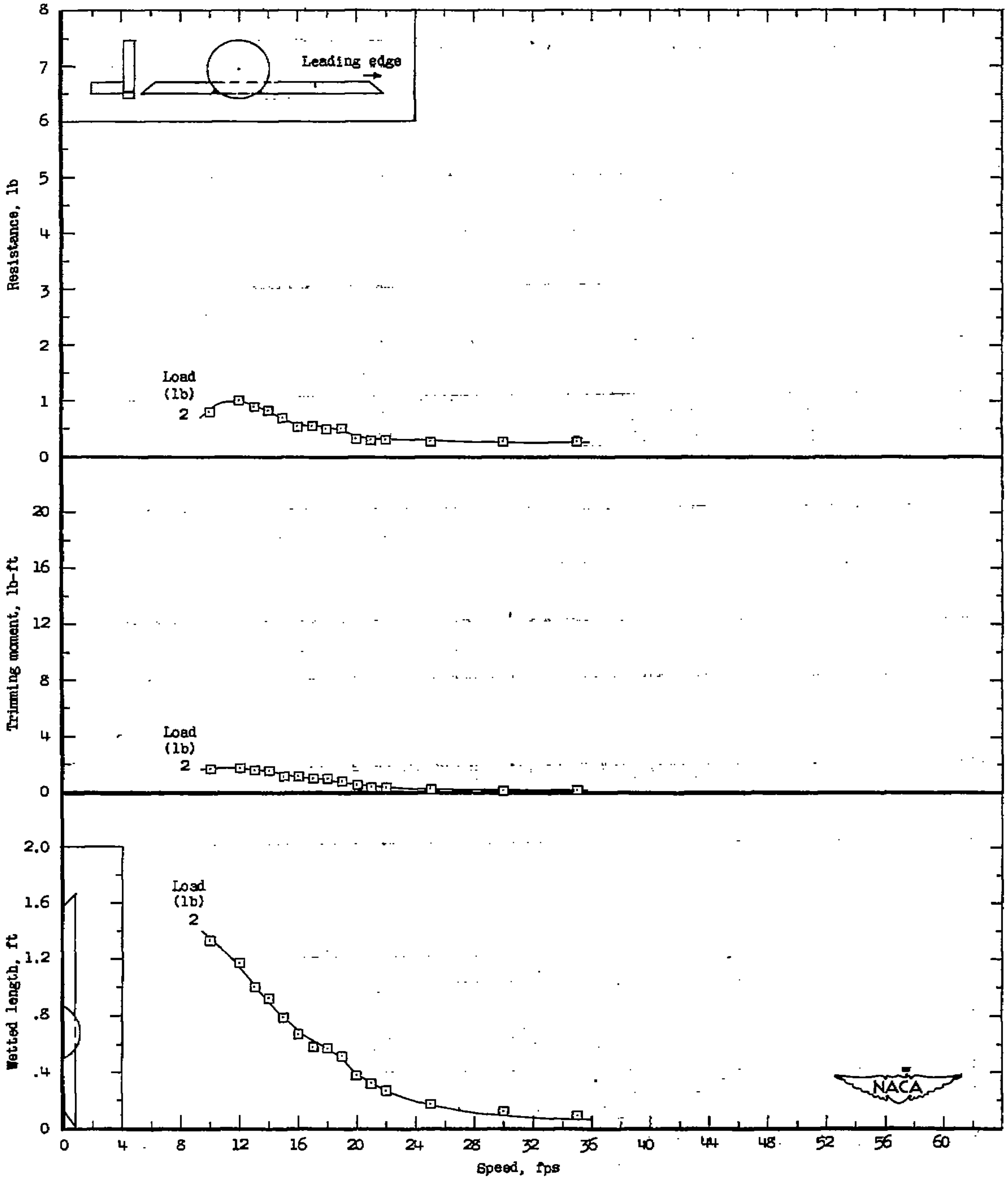


Figure 10.- Model 291A$_3$; trim, 6°; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 60 percent of length of ski; wheel on side of ski; breaker strip on aft side of wheel at bottom of ski.

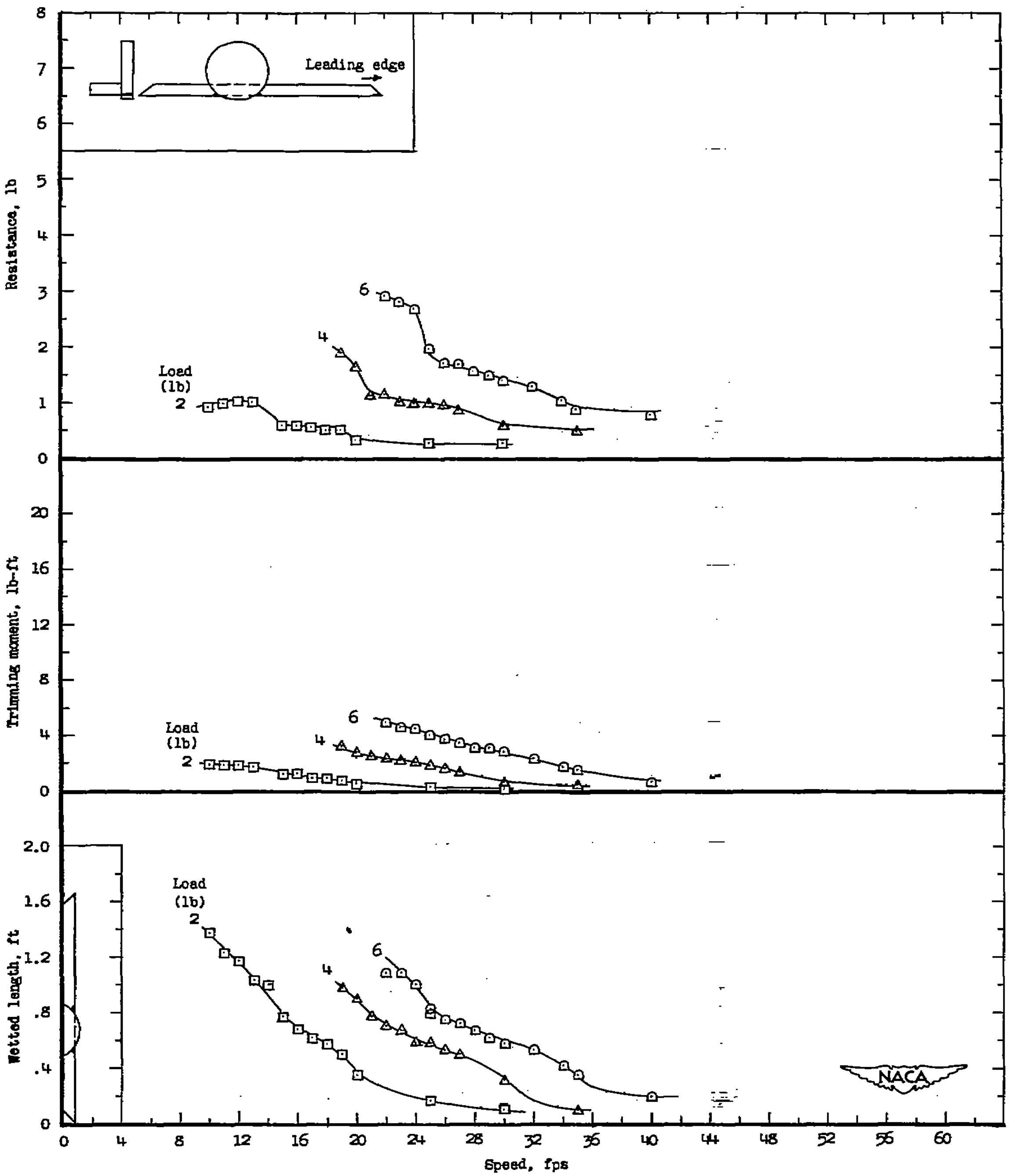


Figure 11.- Model $291A_4$; trim, 6°; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 60 percent of length of ski; wheel on side of ski; breaker strips on fore-and-aft sides of wheel at bottom of ski.

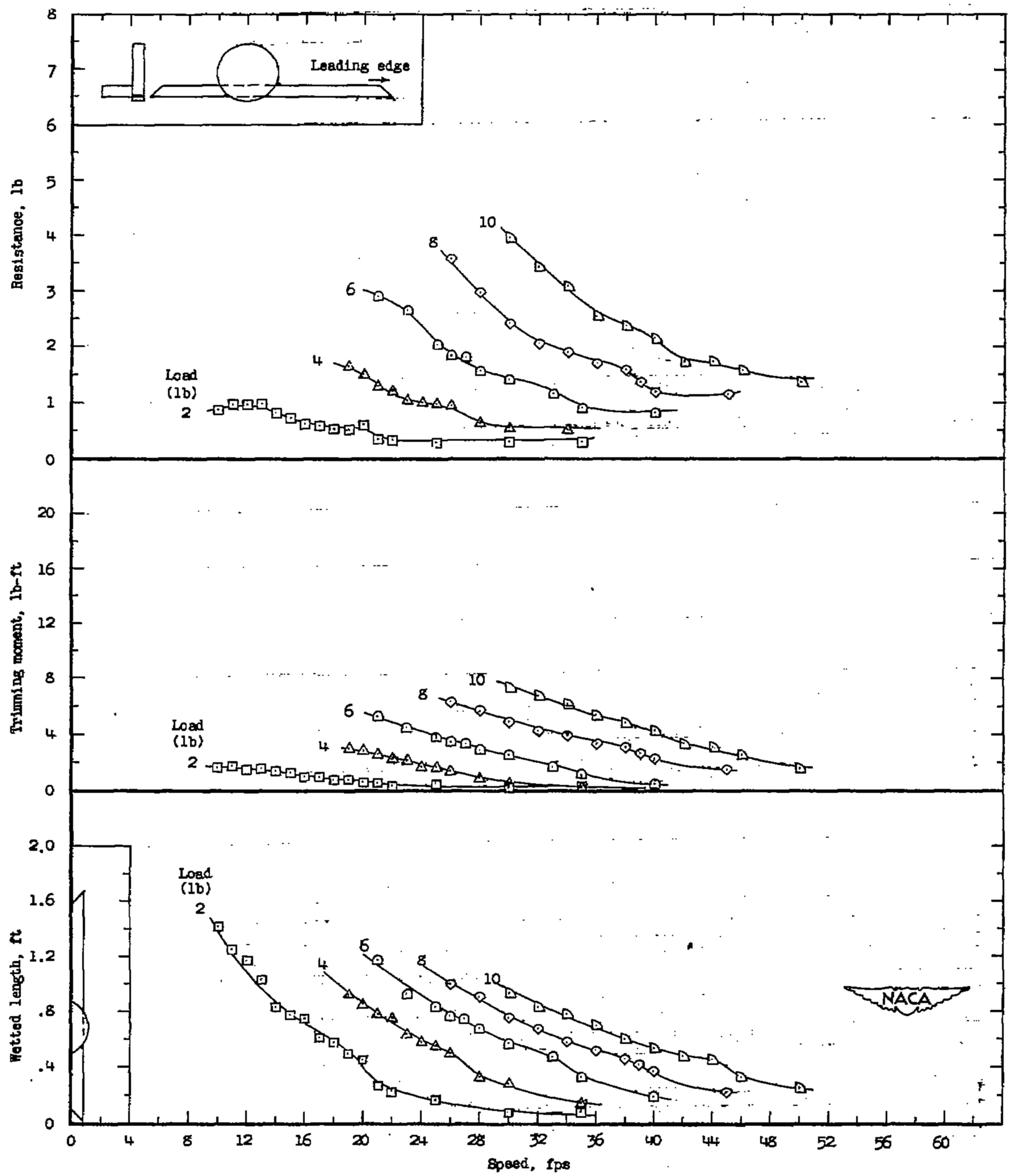
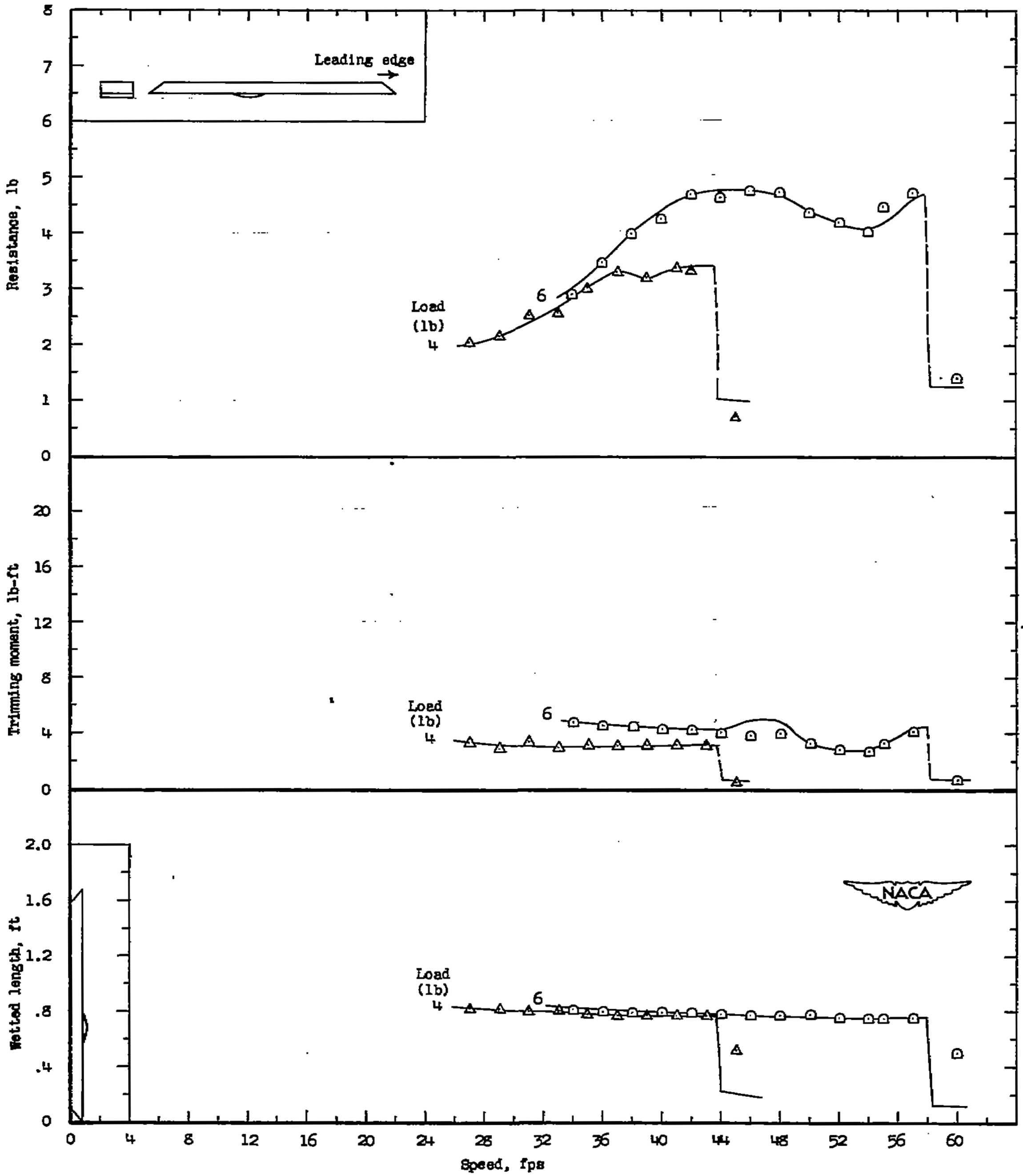
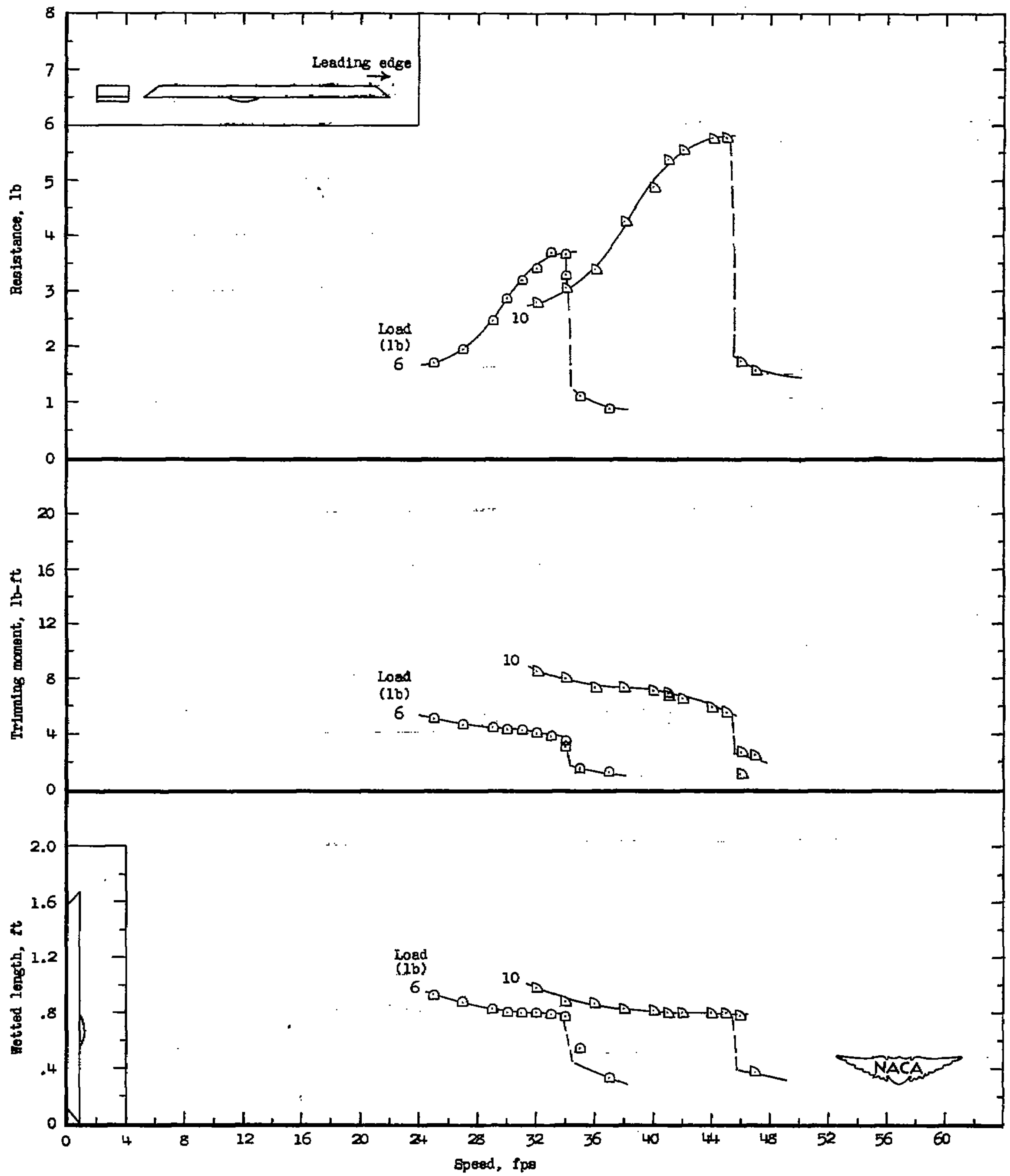


Figure 12.- Model 291A5; trim, 6°; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 60 percent of length of ski; wheel on side of ski; breaker strip on forward side of wheel at deck of ski; breaker strip on aft side of wheel at bottom of ski.



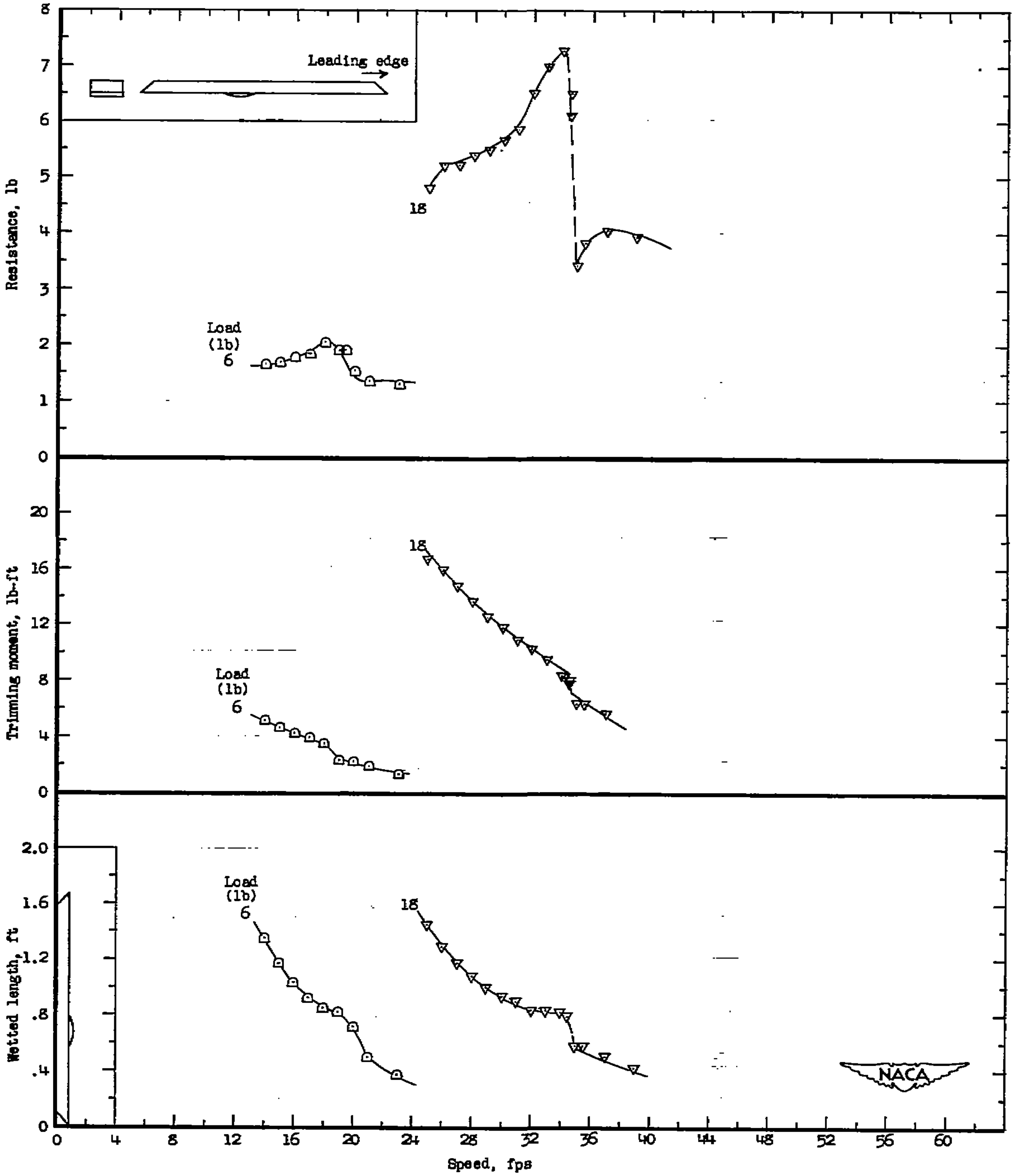
(a) Trim, 4°.

Figure 13.- Model 291B; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 100 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 60 percent of length of ski.



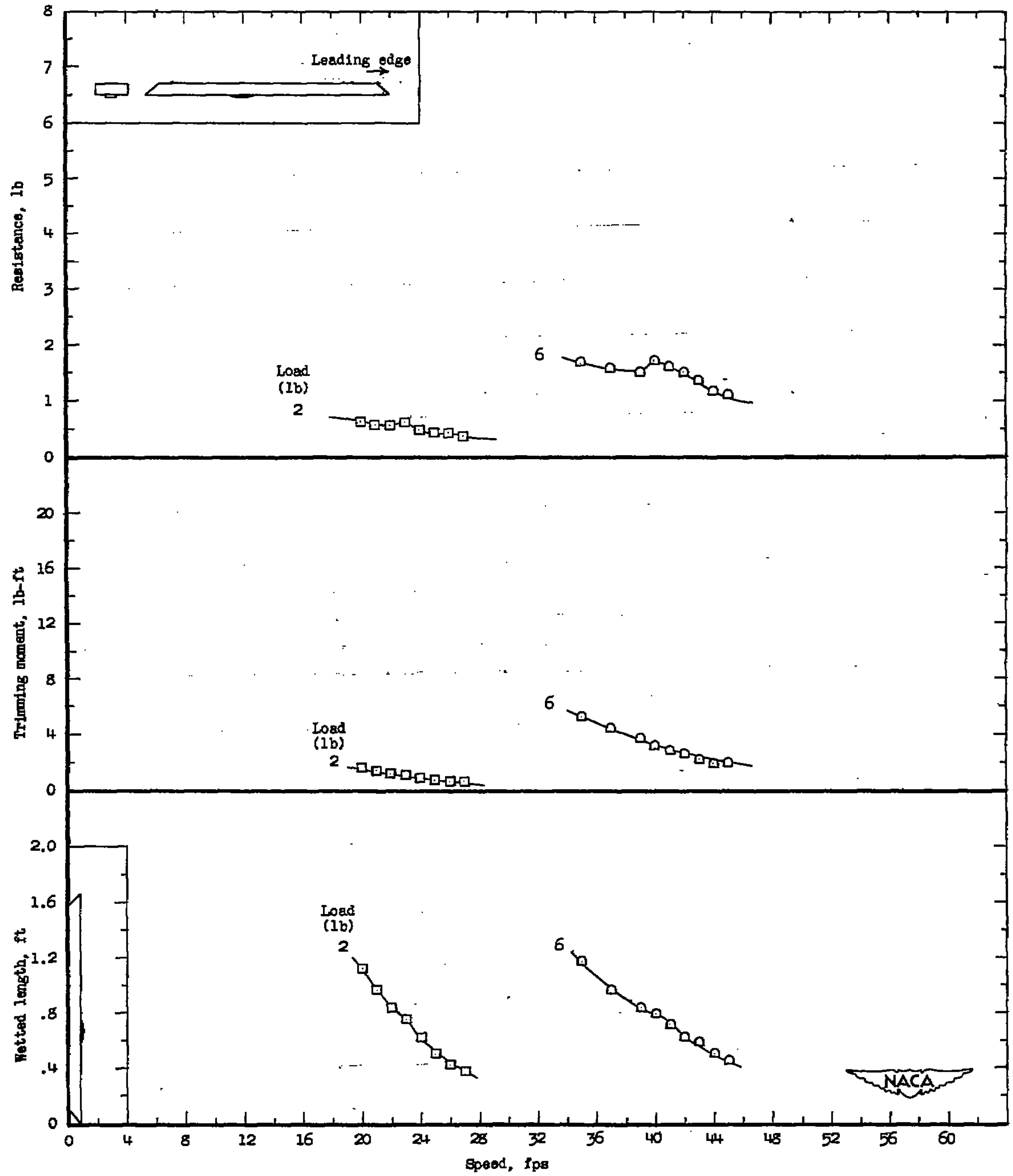
(b) Trim, 6°.

Figure 13.- Continued.



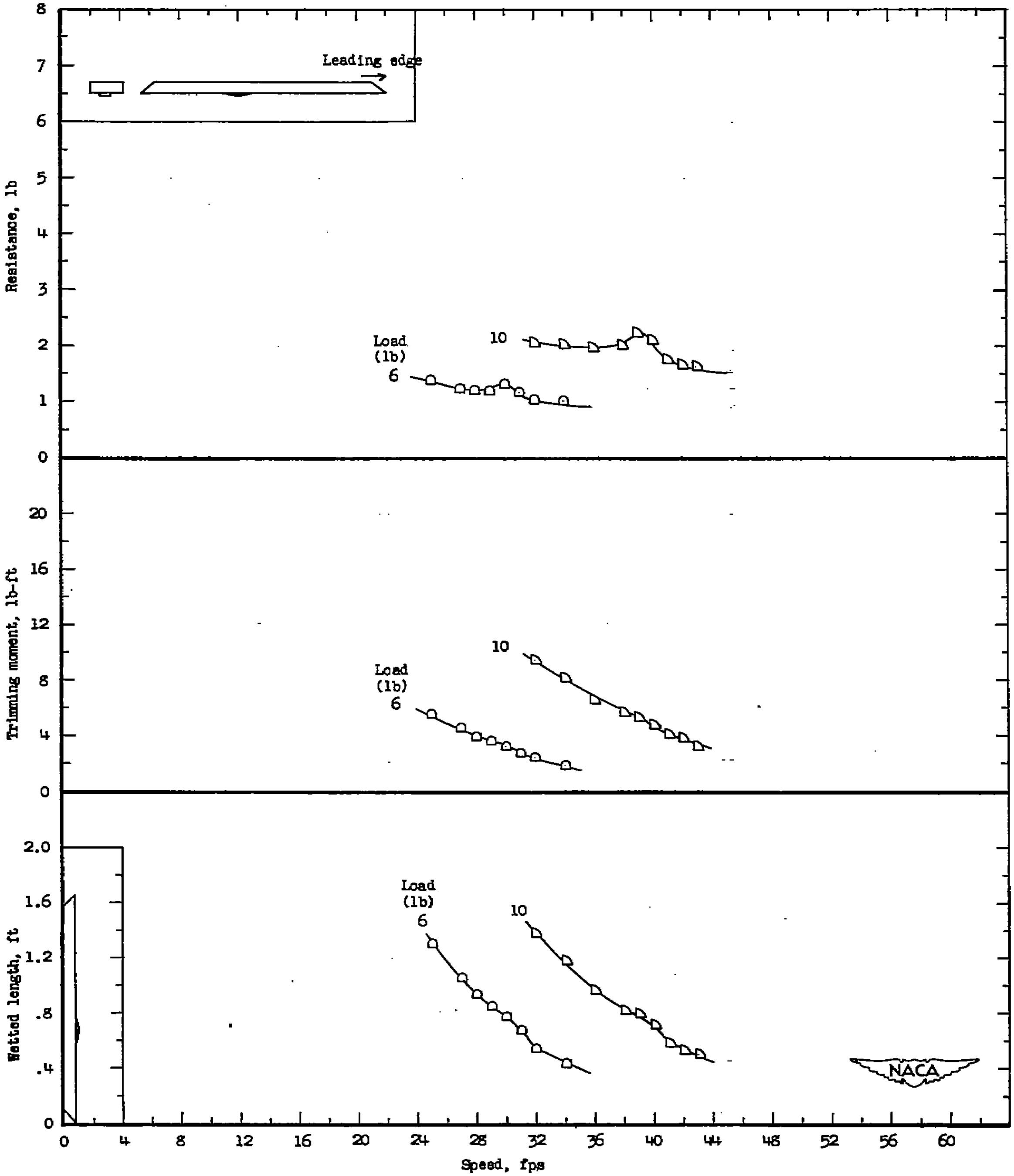
(c) Trim, 12°.

Figure 13.- Concluded.



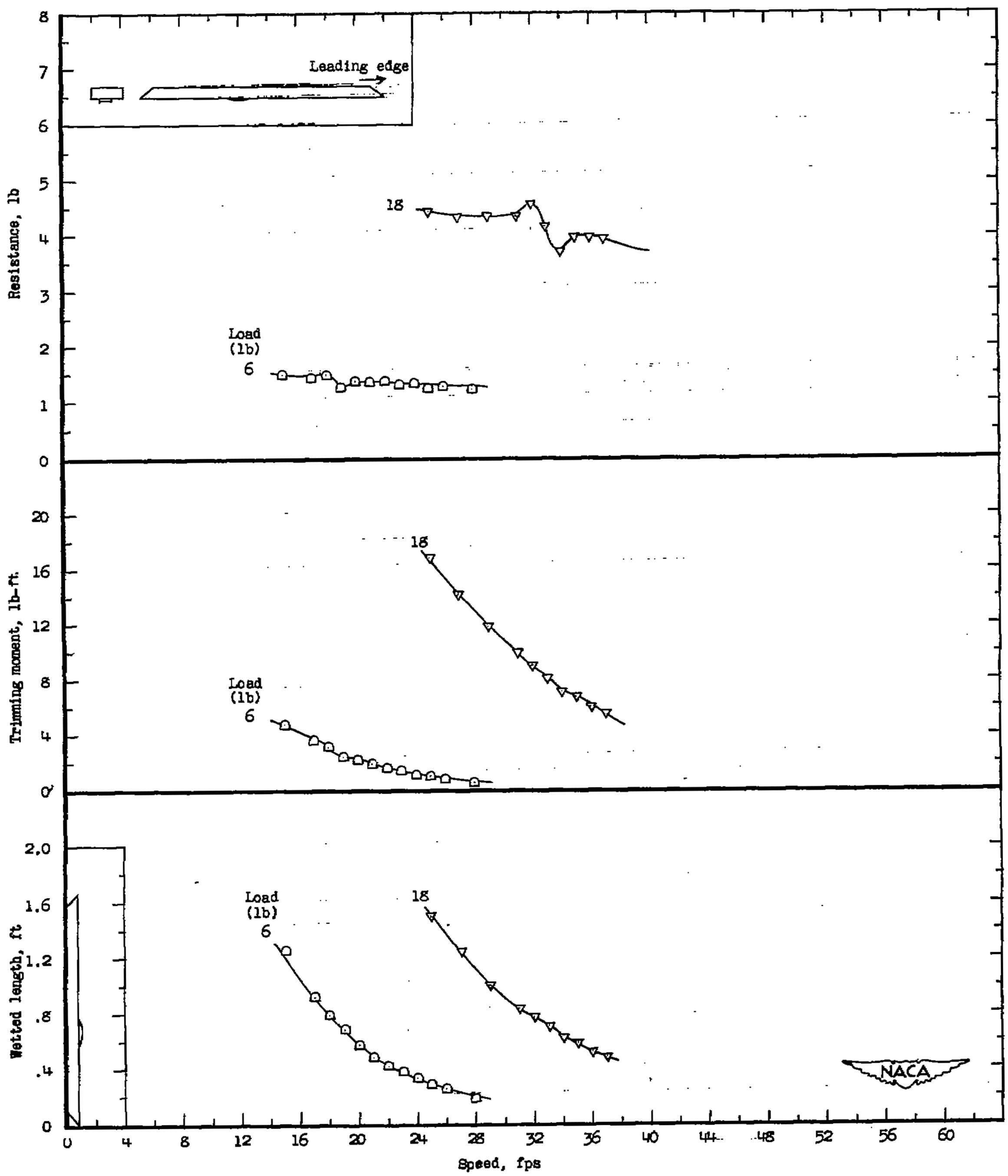
(a) Trim, 4°.

Figure 14.- Model 291C; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 3.75 percent of diameter of wheel; center of wheel at 60 percent of length of ski.



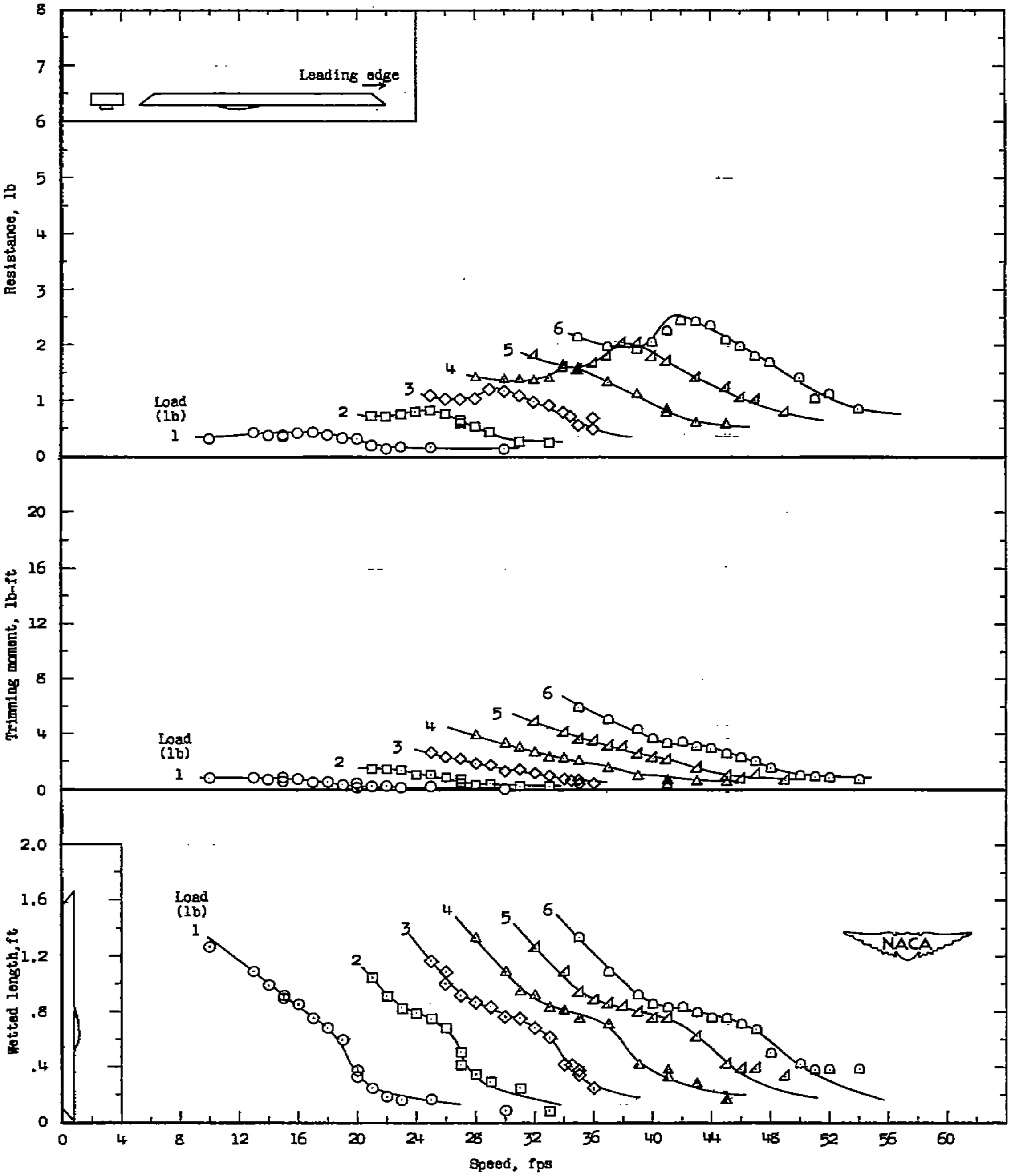
(b) Trim, 6°.

Figure 14.- Continued.



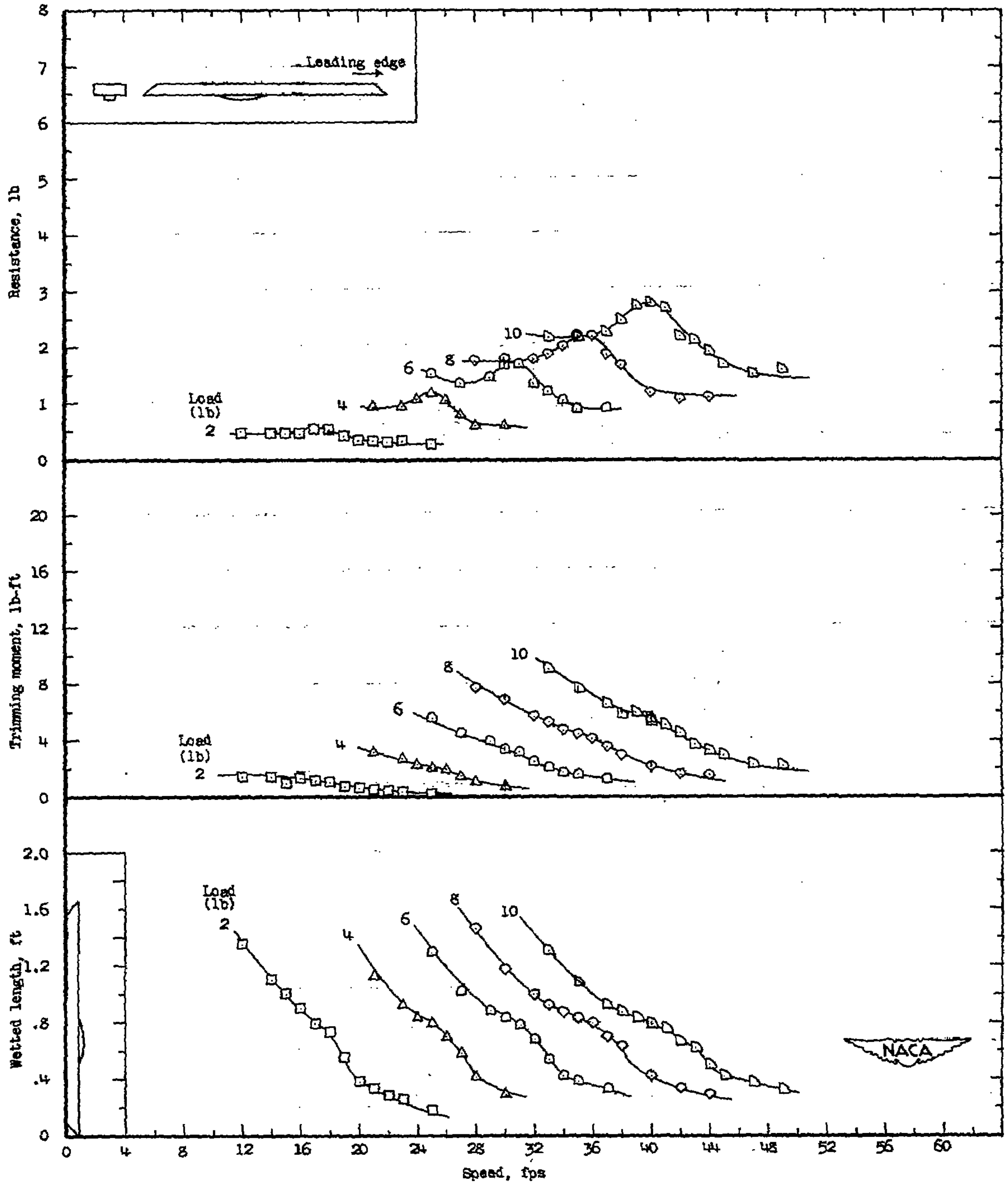
(c) Trim, 12°.

Figure 14.- Concluded.



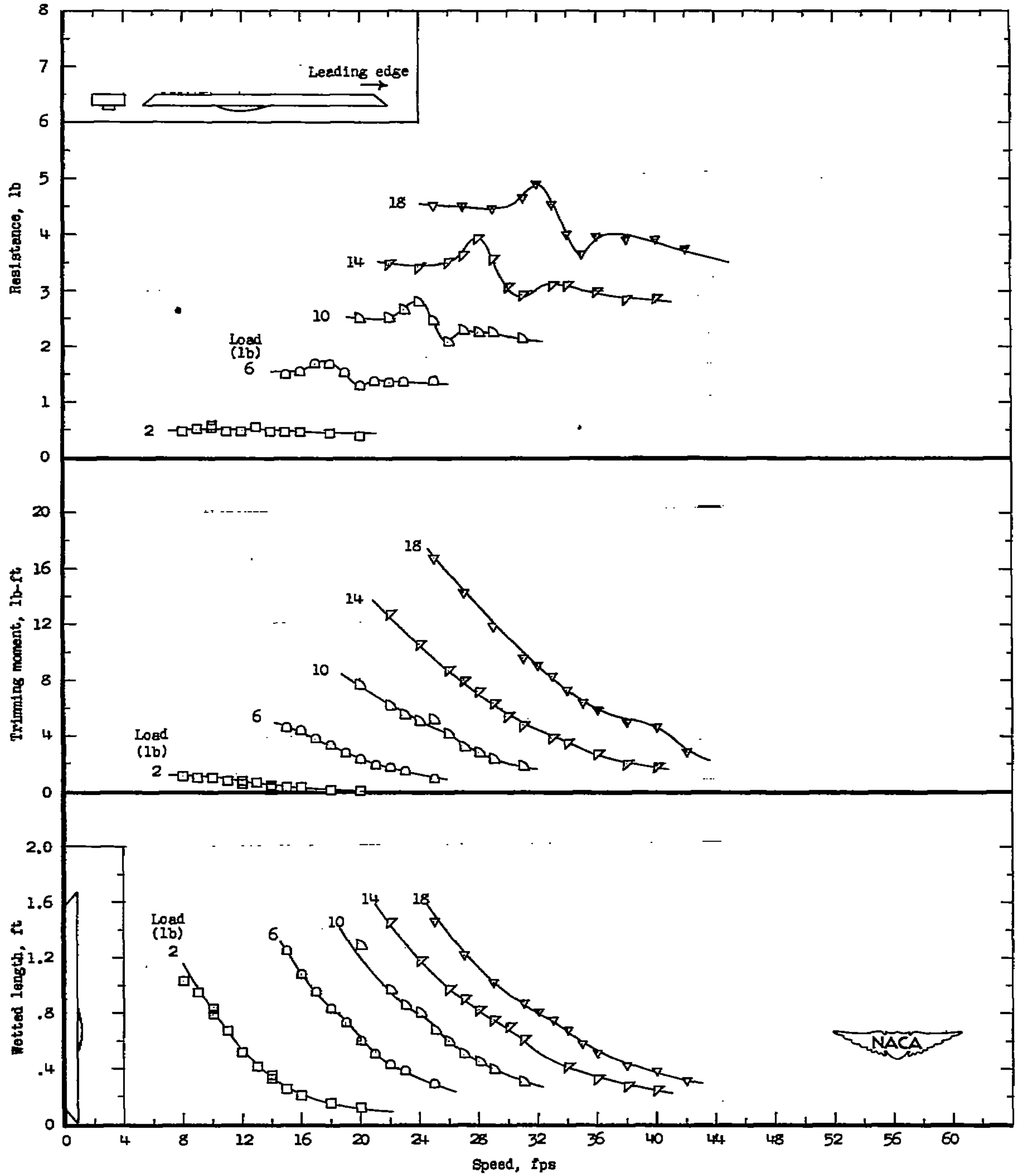
(a) Trim, 4°.

Figure 15.- Model 291D; dead rise, 0°; wheel diameter, 50 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 60 percent of length of ski.



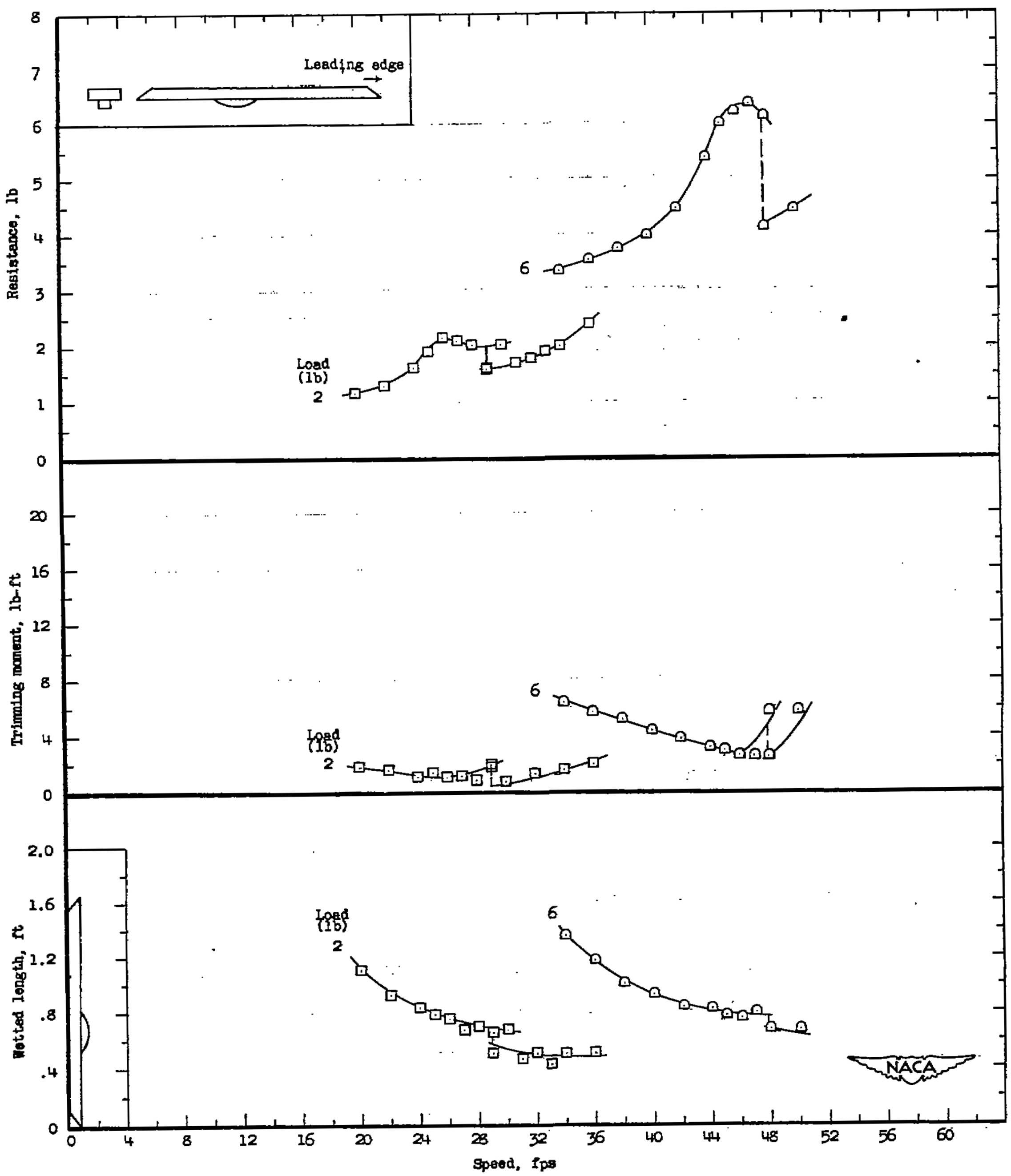
(b) Trim, 6°.

Figure 15.- Continued.



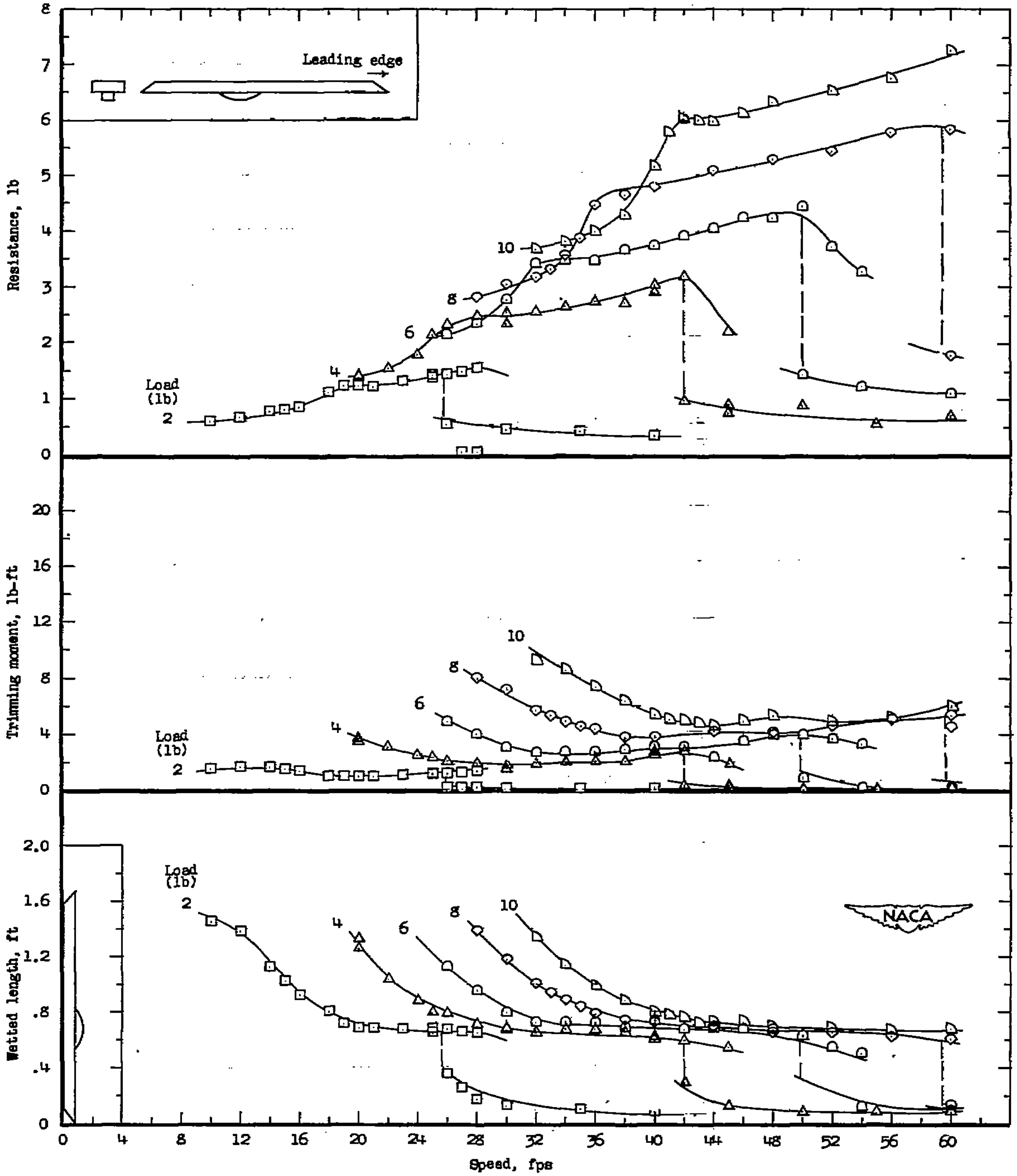
(c) Trim, 12°.

Figure 15.- Concluded.



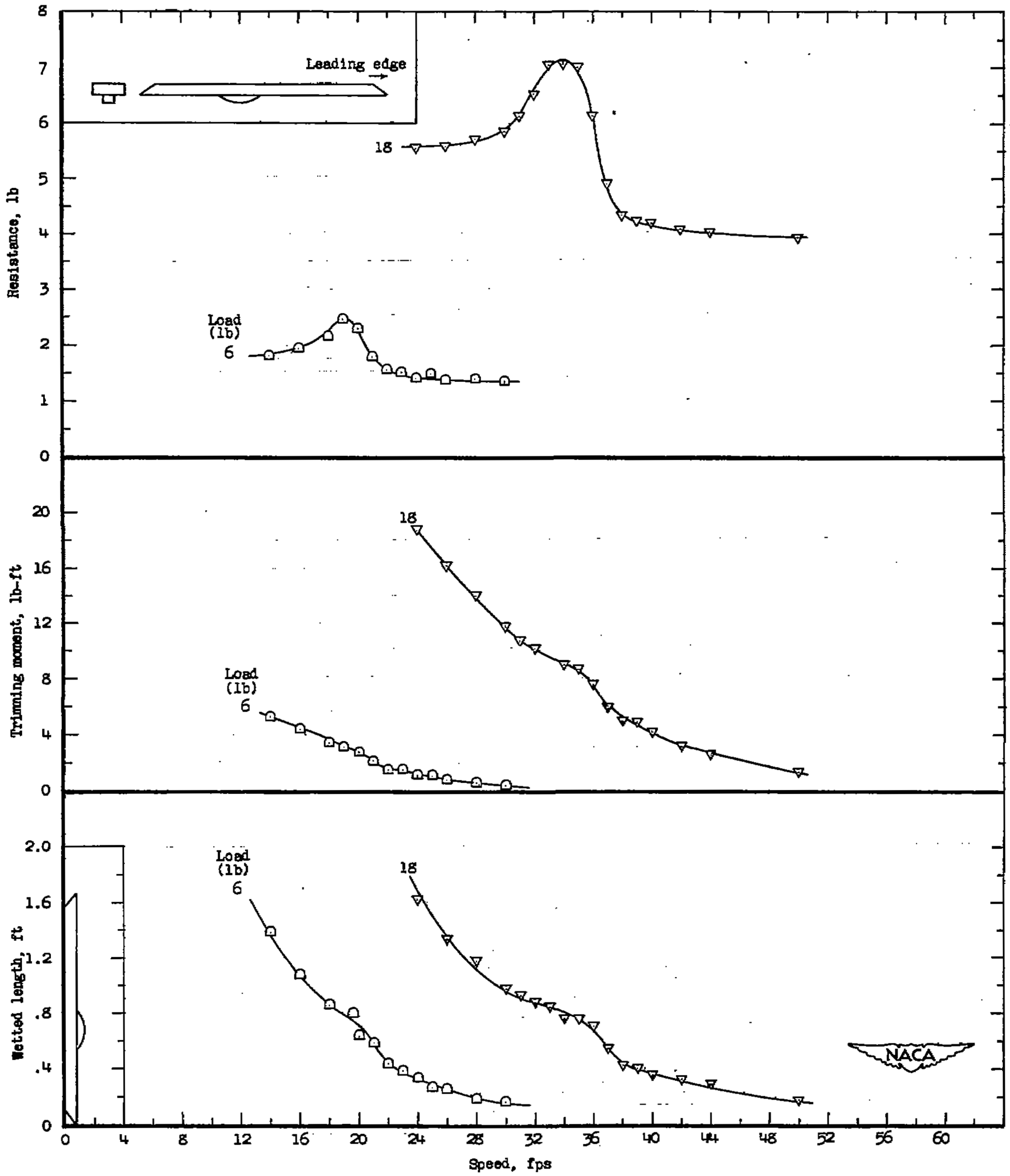
(a) Trim, 4°.

Figure 16.- Model 291E; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 15 percent of diameter of wheel; center of wheel at 60 percent of length of ski.



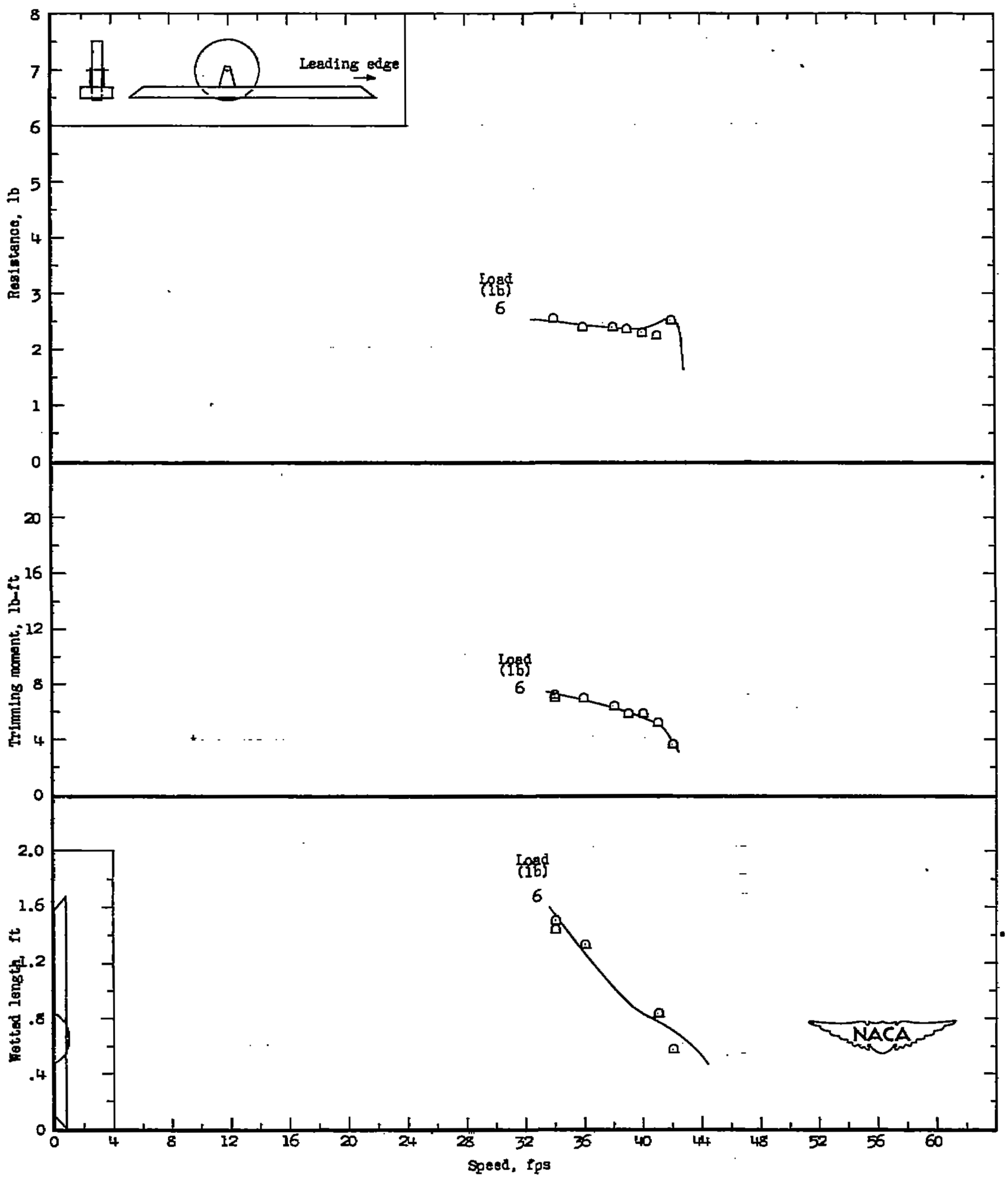
(b) Trim, 6°.

Figure 16.- Continued.



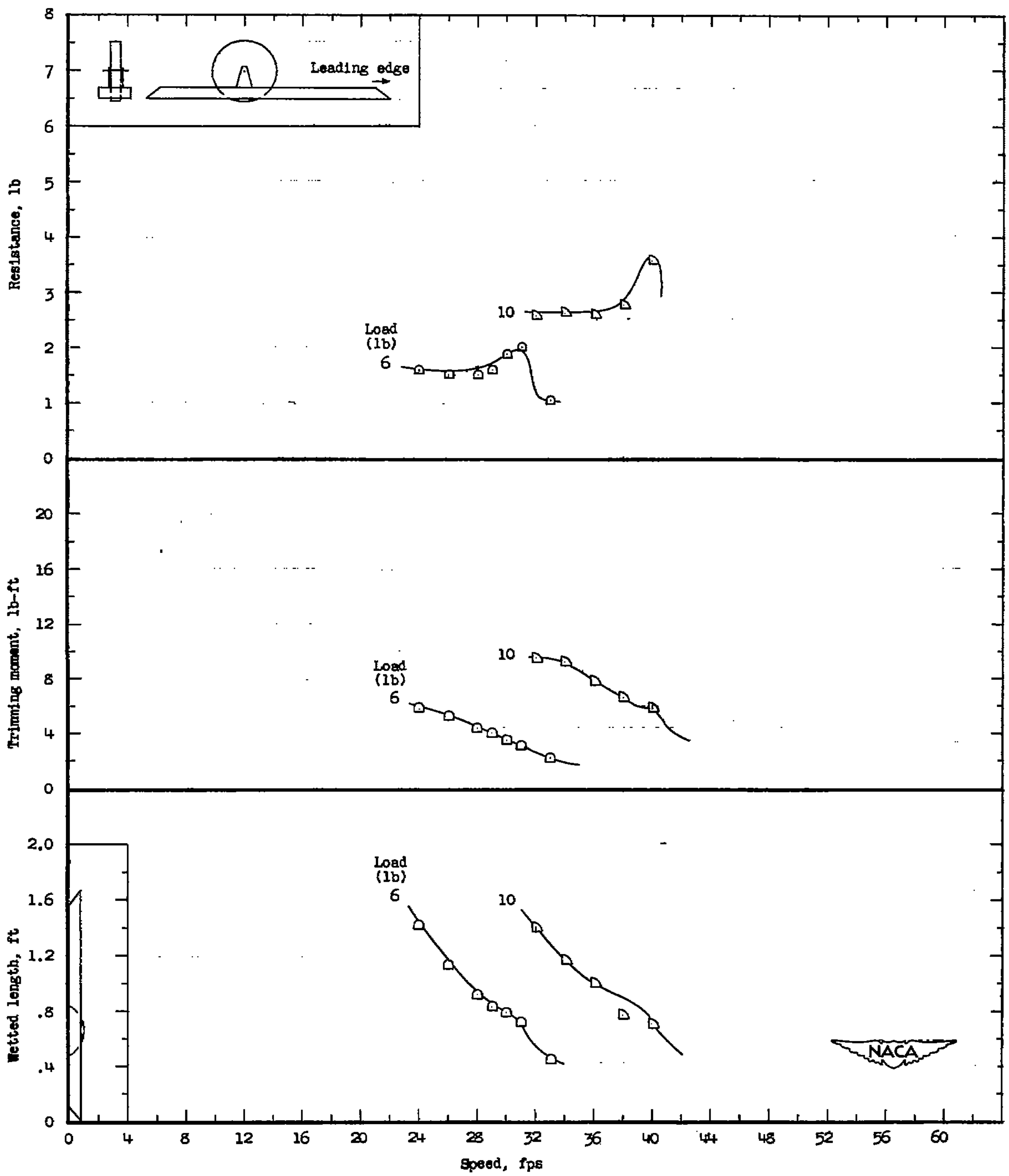
(c) Trim, 12°.

Figure 16.- Concluded.



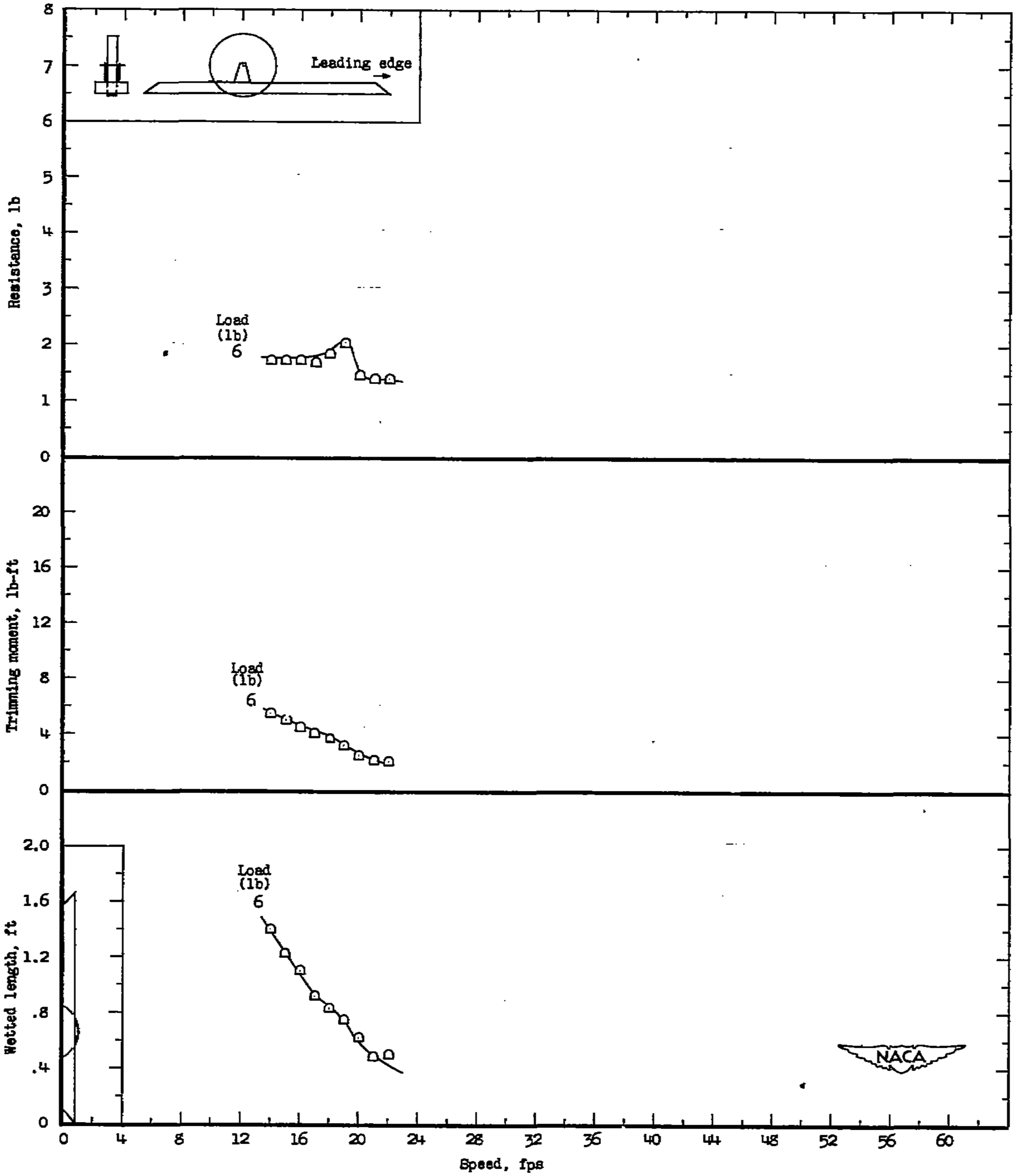
(a) Trim, 4°.

Figure 17.- Model 291F; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 3.75 percent of diameter of wheel; center of wheel at 60 percent of length of ski; wheel fixed; $\frac{1}{16}$ -inch gap between wheel and ski.



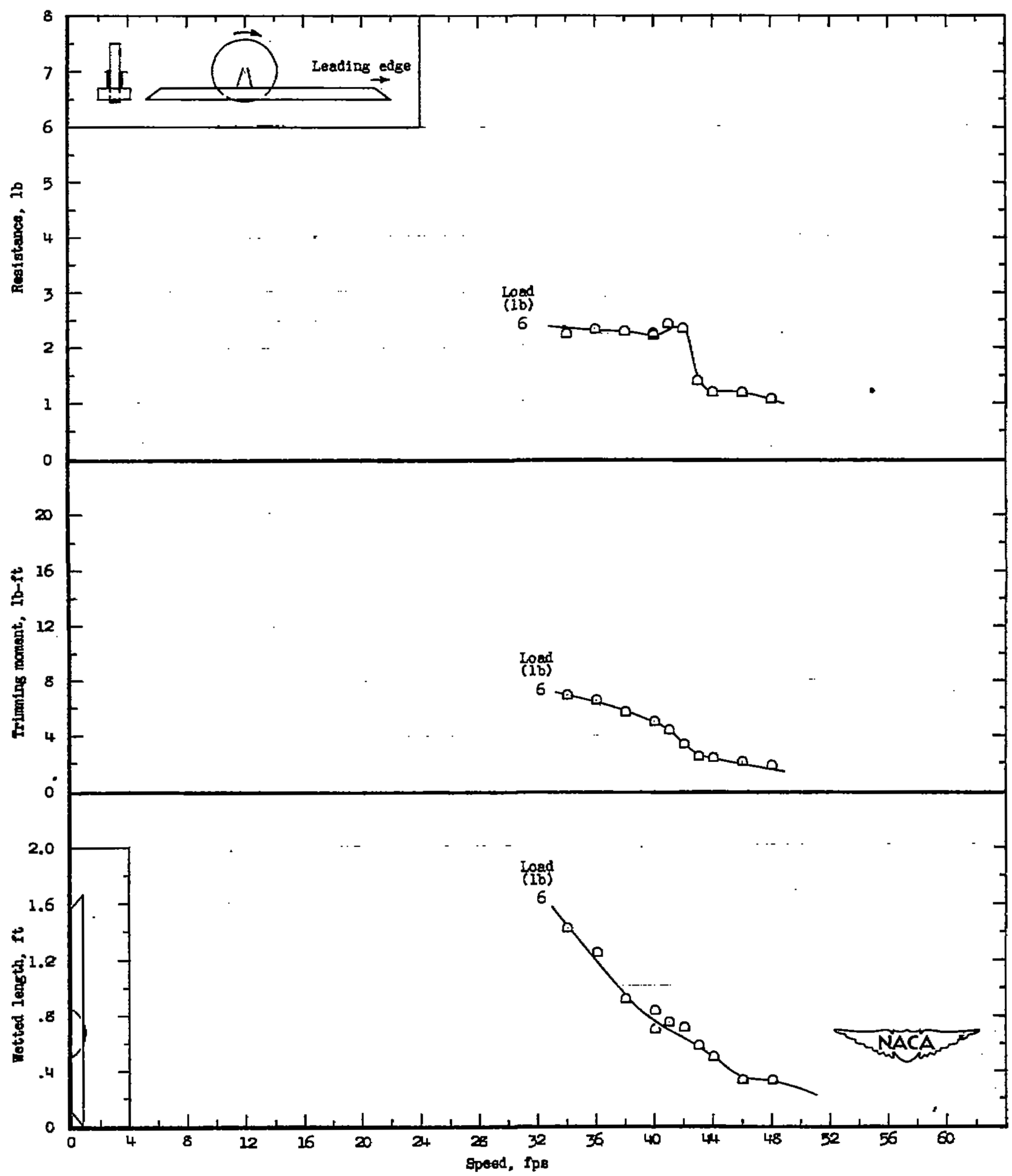
(b) Trim, 6°.

Figure 17.- Continued.



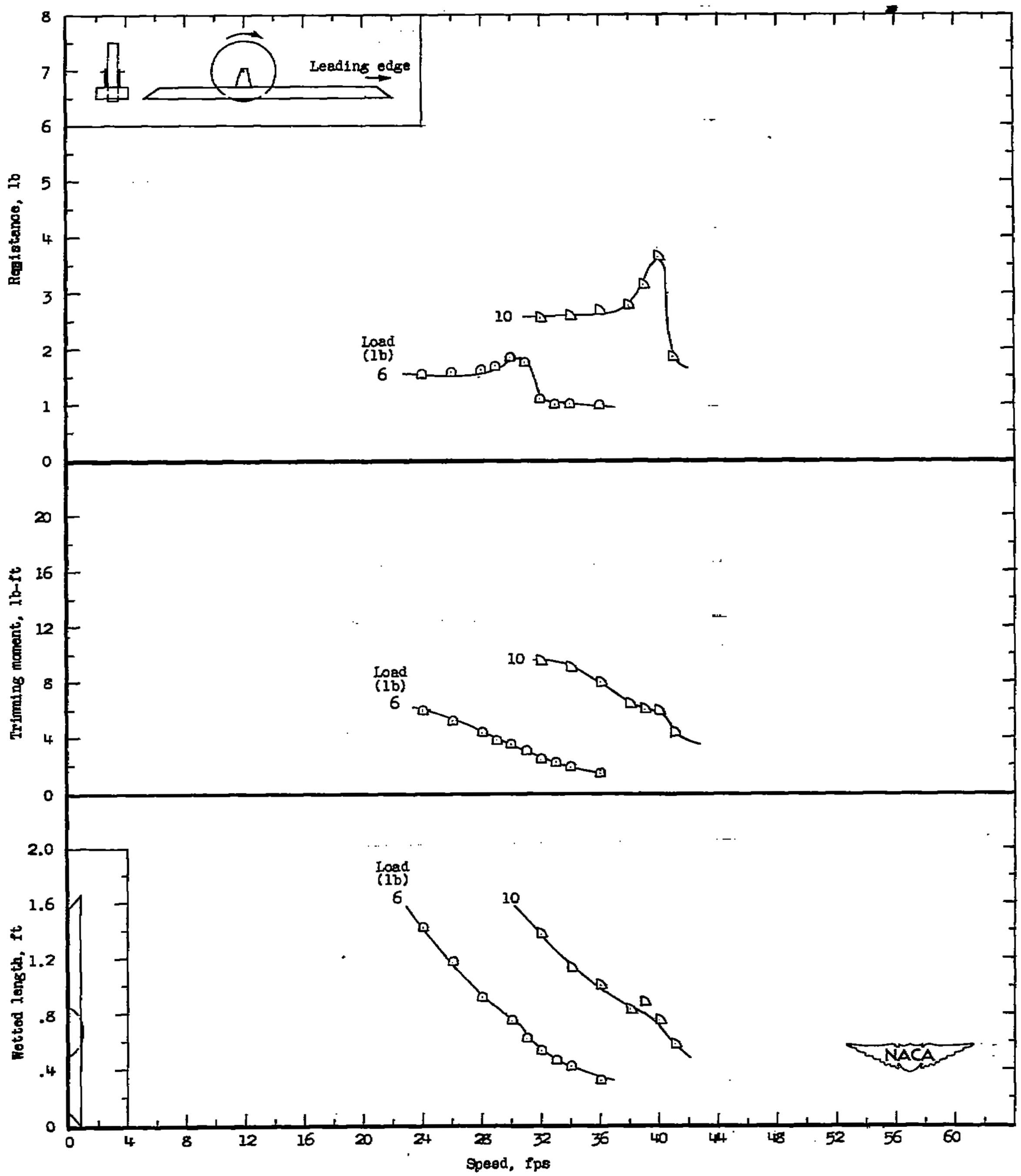
(c) Trim, 12°.

Figure 17.- Concluded.



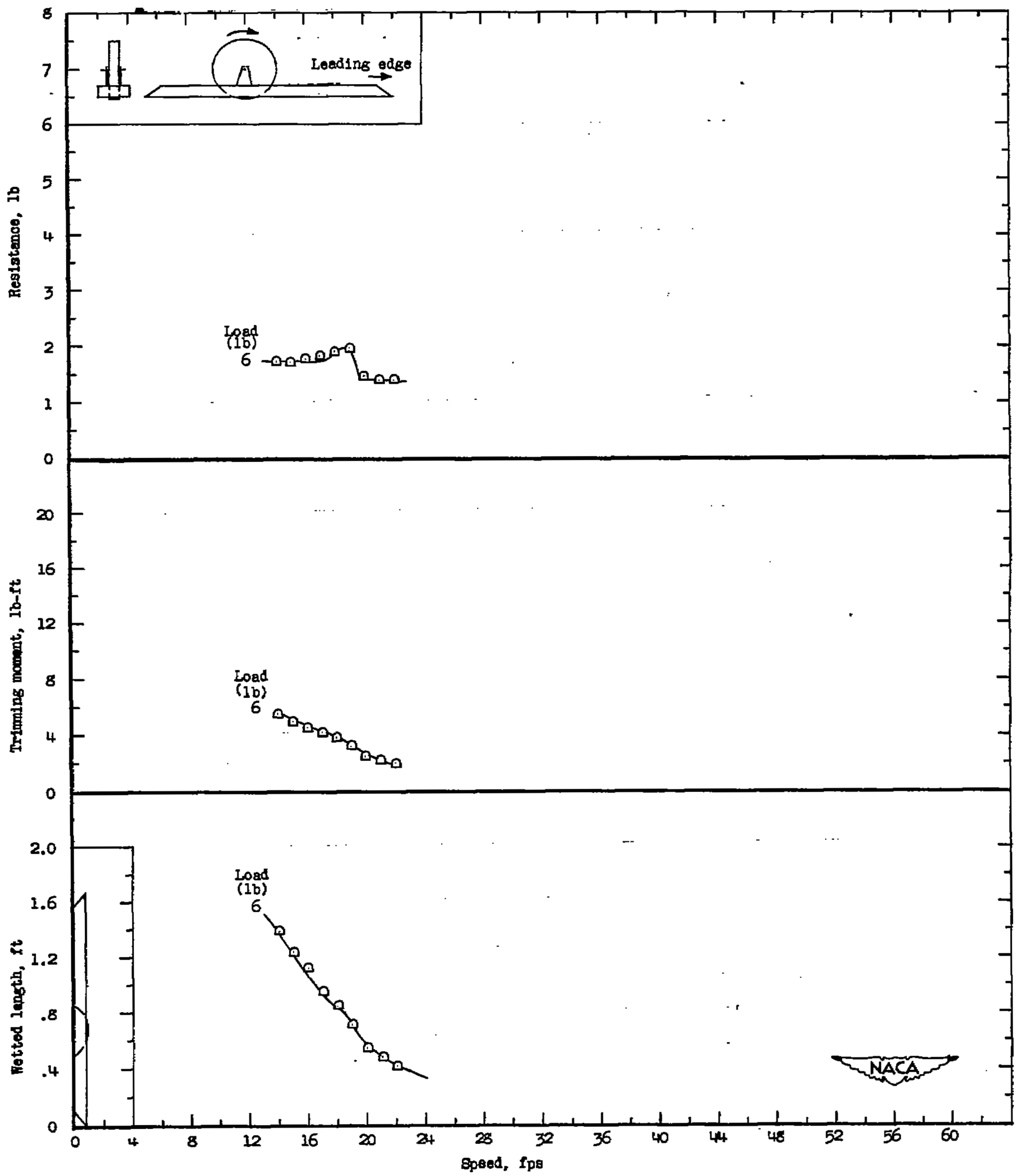
(a) Trim, 4°.

Figure 18.- Model $291F_1$; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 3.75 percent of diameter of wheel; center of wheel at 60 percent of length of ski; wheel free to rotate; $\frac{1}{16}$-inch gap between wheel and ski.



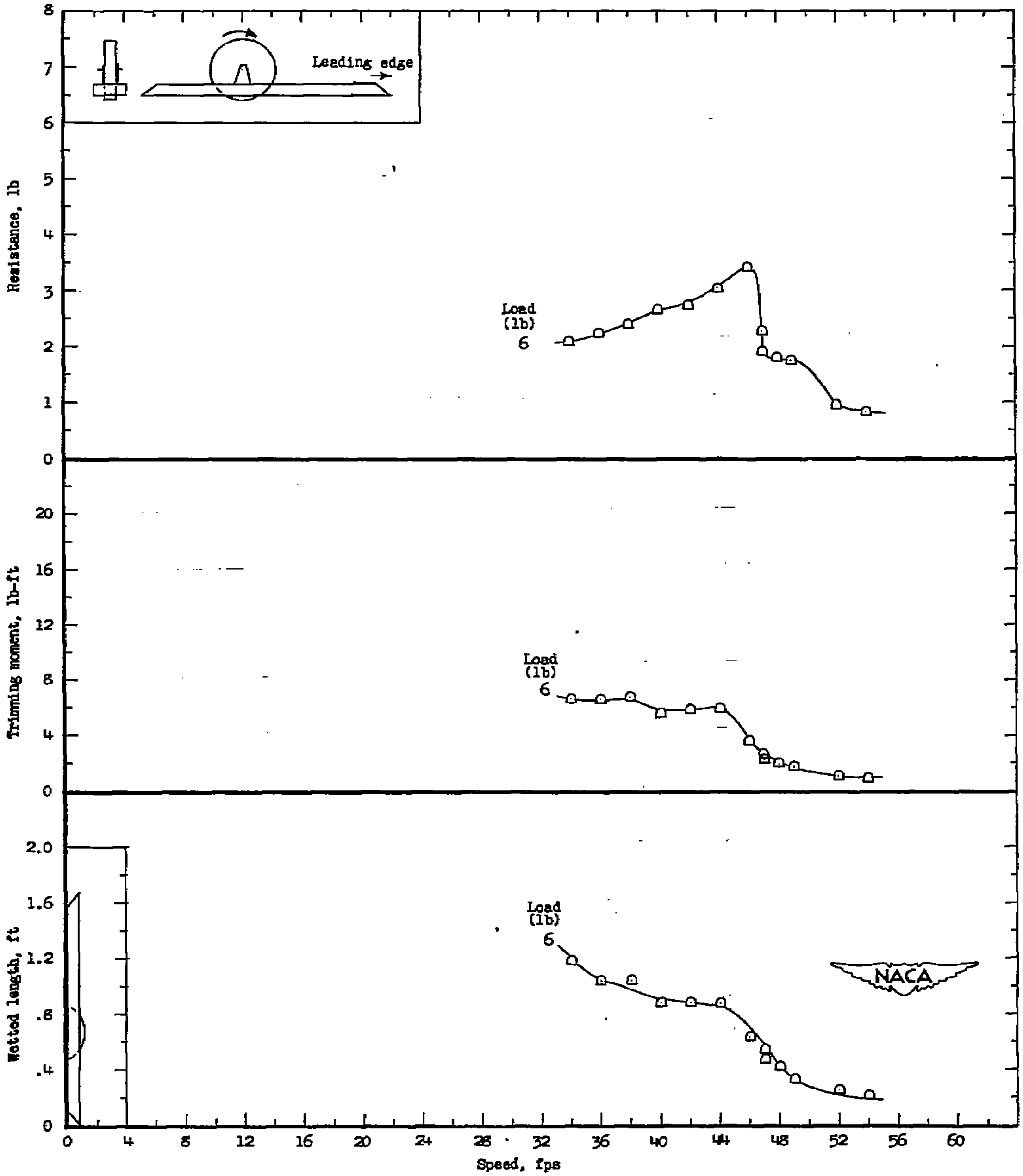
(b) Trim, 6°.

Figure 18.- Continued.



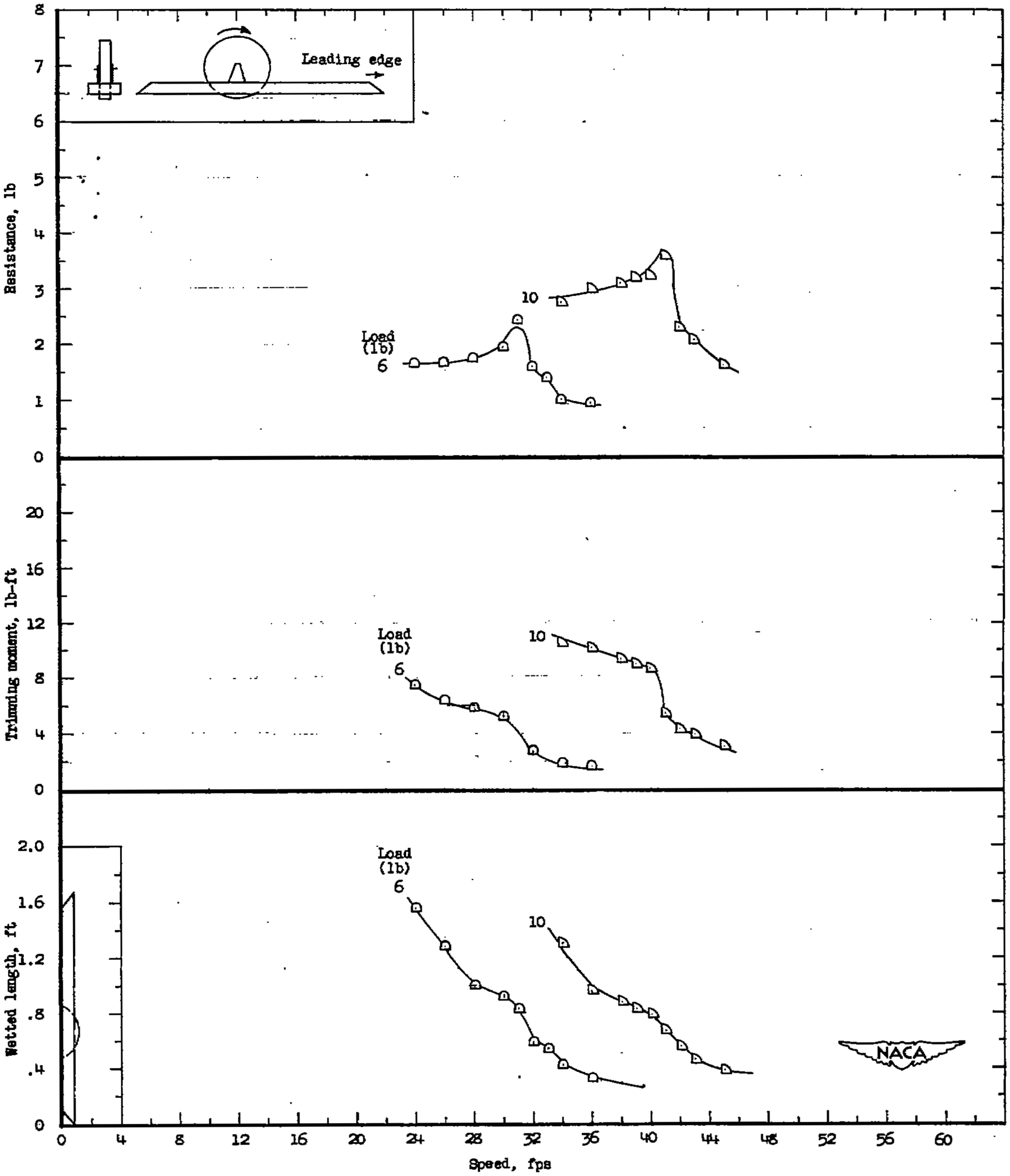
(c) Trim, 12°.

Figure 18.- Concluded.



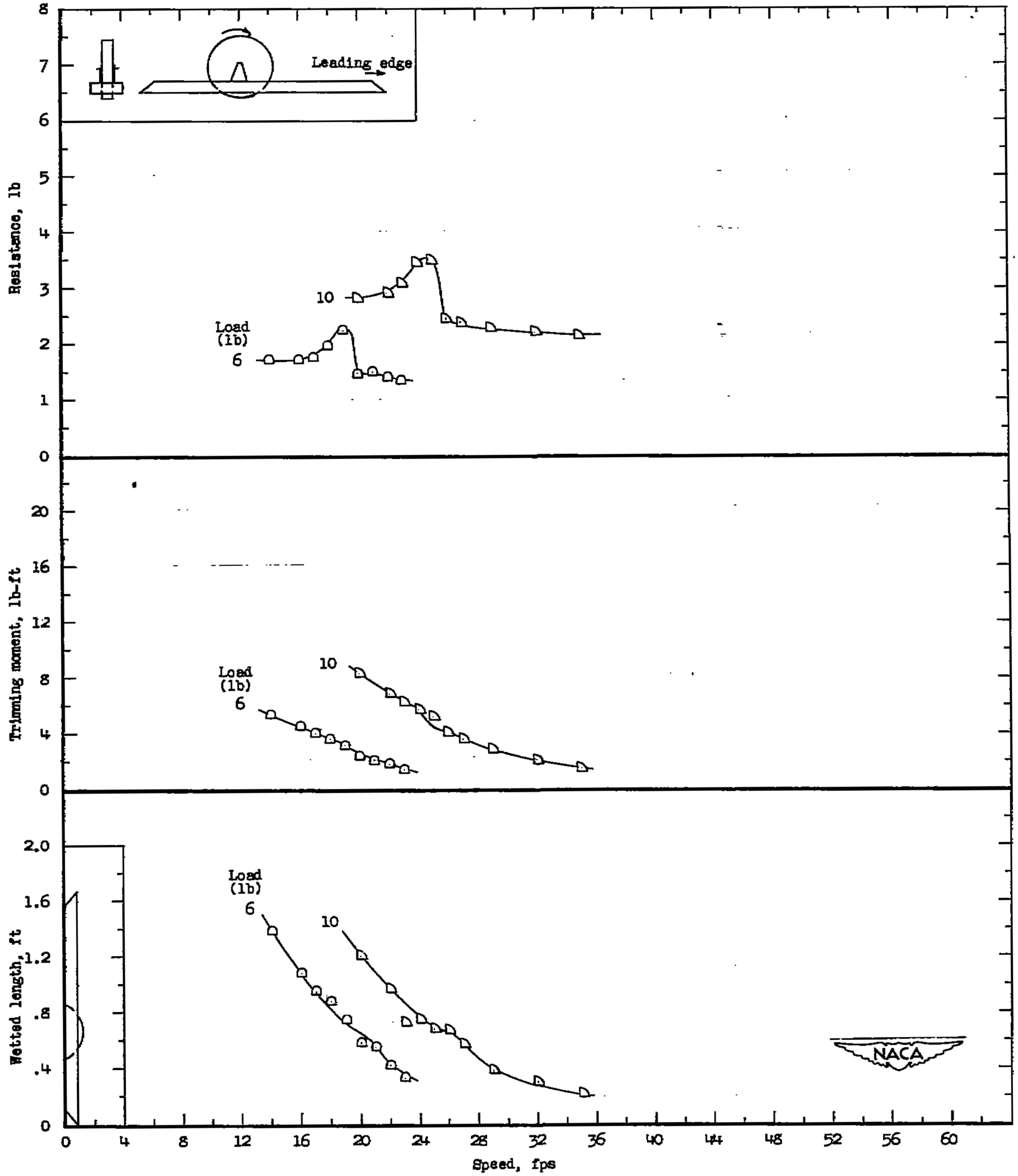
(a) Trim, 4°.

Figure 19.- Model 291G; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 60 percent of length of ski; wheel free to rotate; $\frac{1}{16}$- inch gap between wheel and ski.



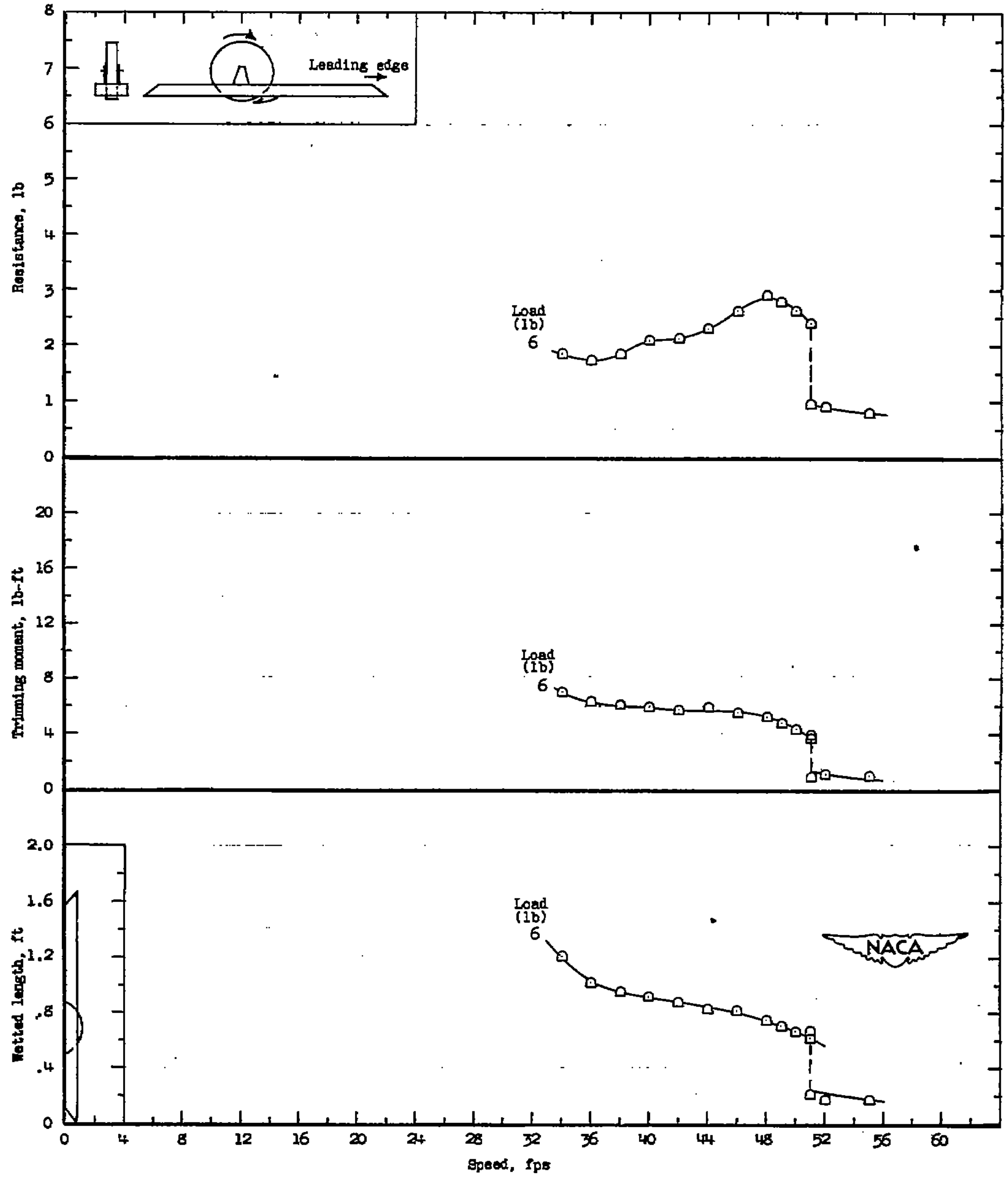
(b) Trim, 6°.

Figure 19.- Continued.



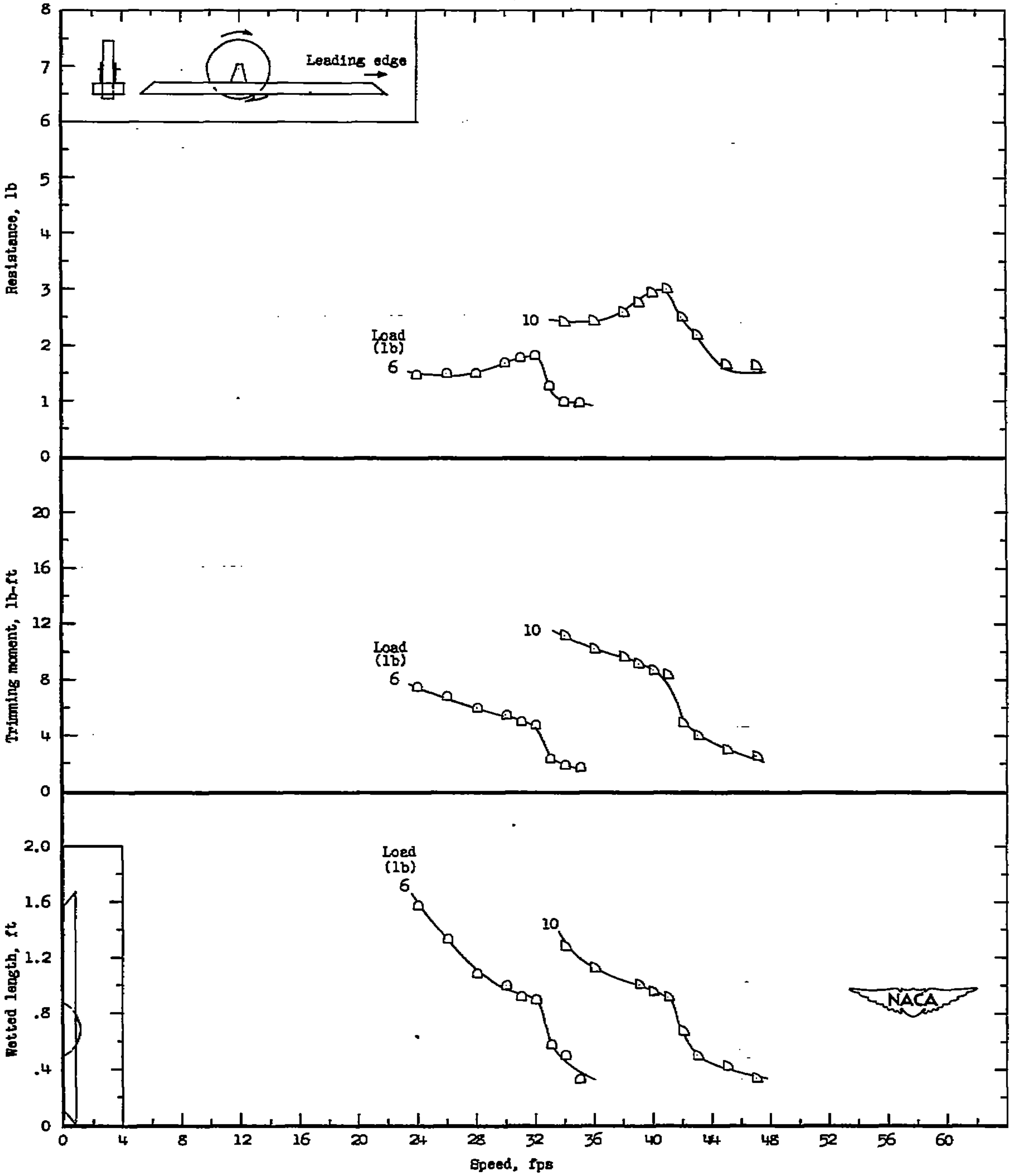
(c) Trim, 12°.

Figure 19.- Concluded.



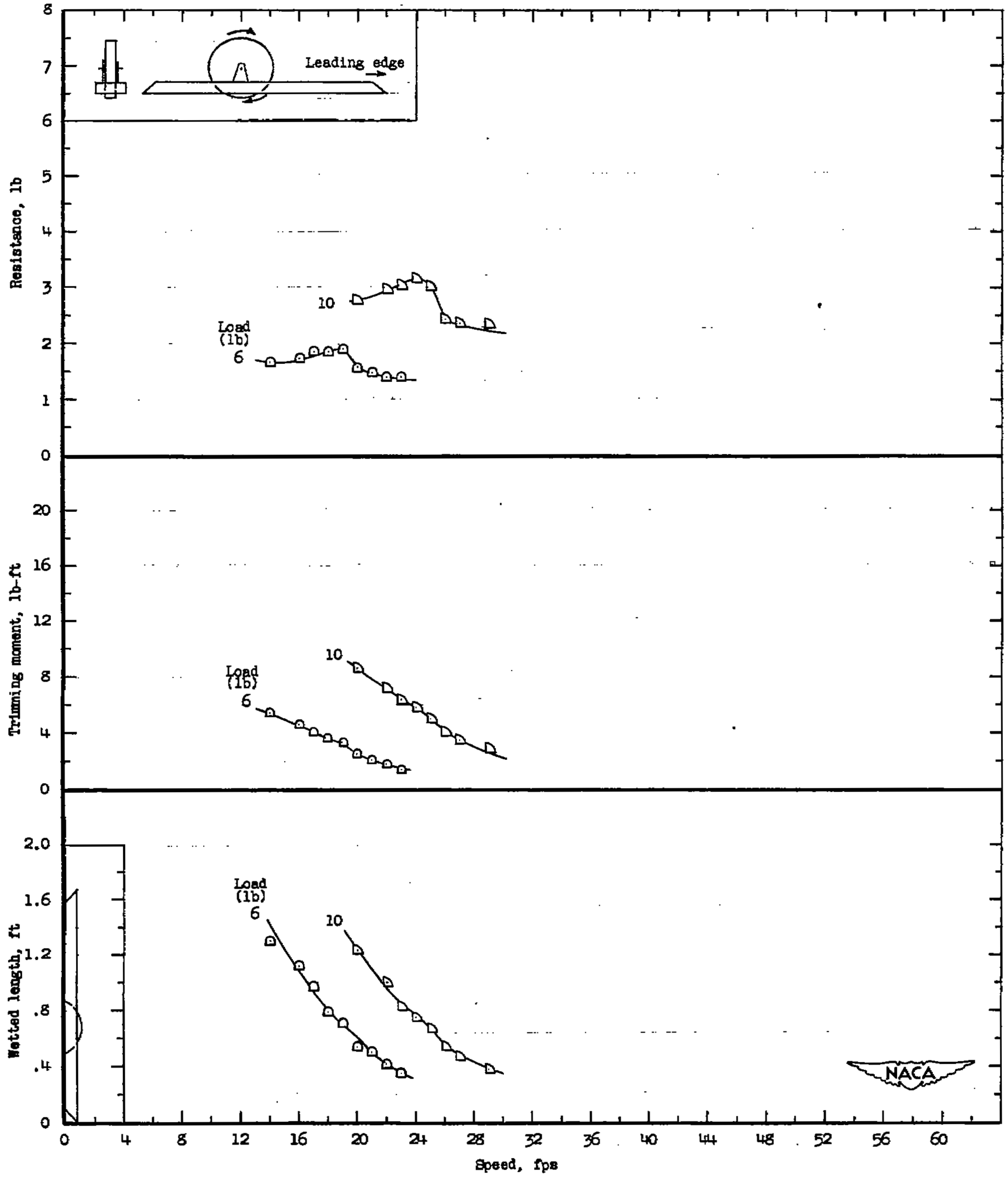
(a) Trim, 4°.

Figure 20.- Model $291G_1$; dead rise, 0°; wheel diameter, 25 percent of length of ski; wheel width, 35 percent of beam of ski; protrusion, 7.50 percent of diameter of wheel; center of wheel at 60 percent of length of ski; wheel free to rotate; $\frac{1}{16}$-inch gap between wheel and ski; 2.0-inch fairing forward of wheel on bottom of ski.



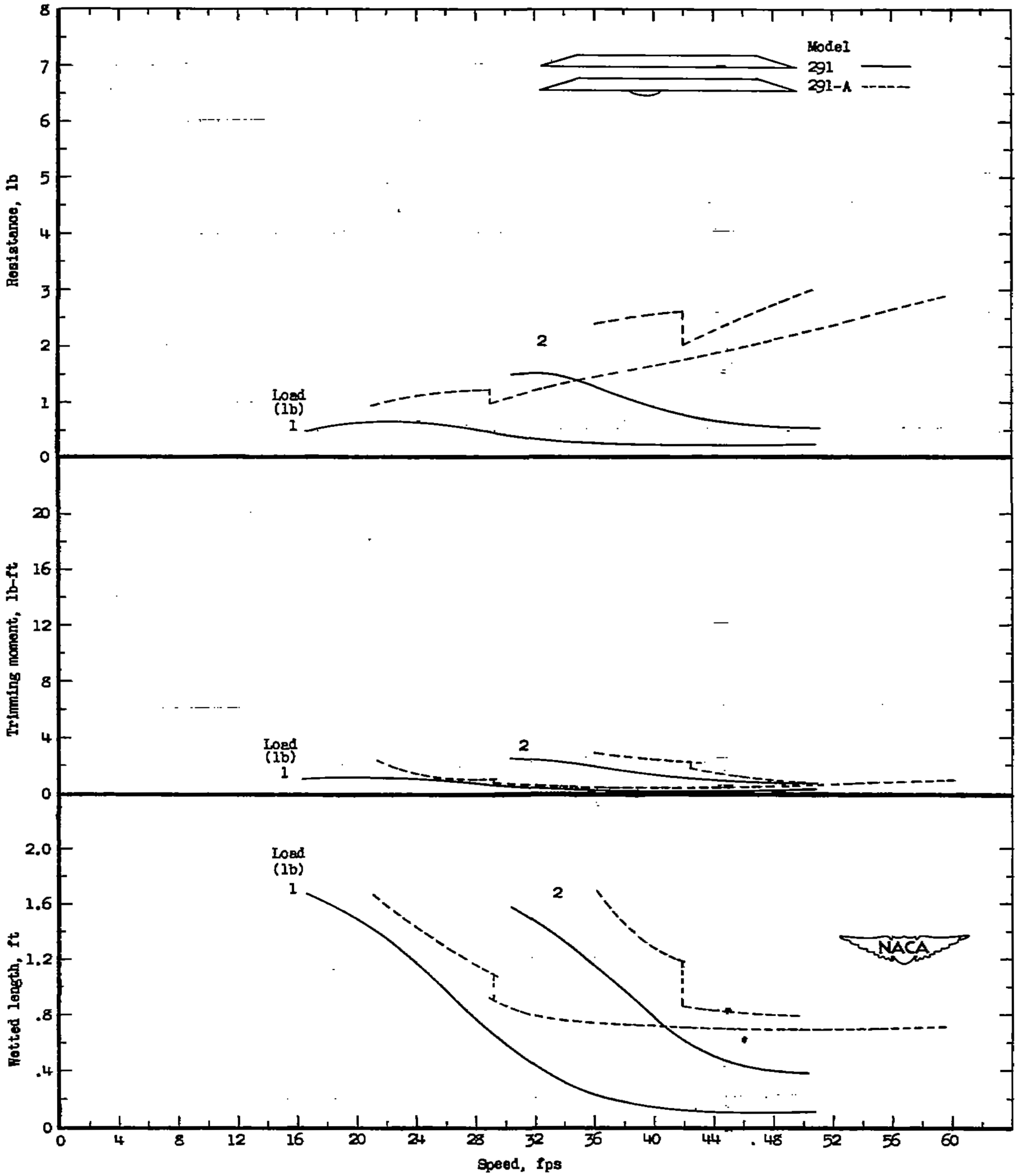
(b) Trim, 6°.

Figure 20.- Continued.



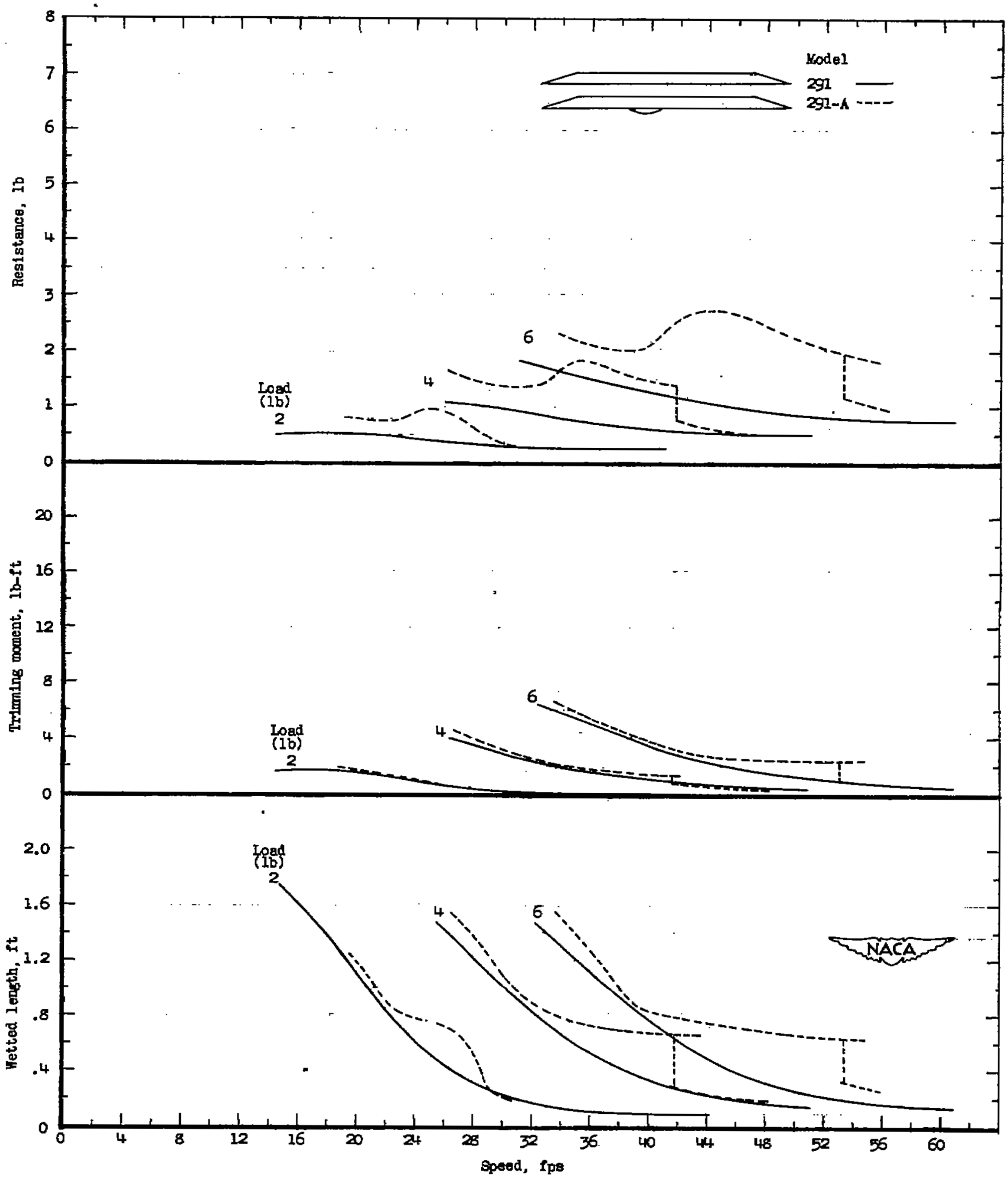
(c) Trim, 12°.

Figure 20.- Concluded.



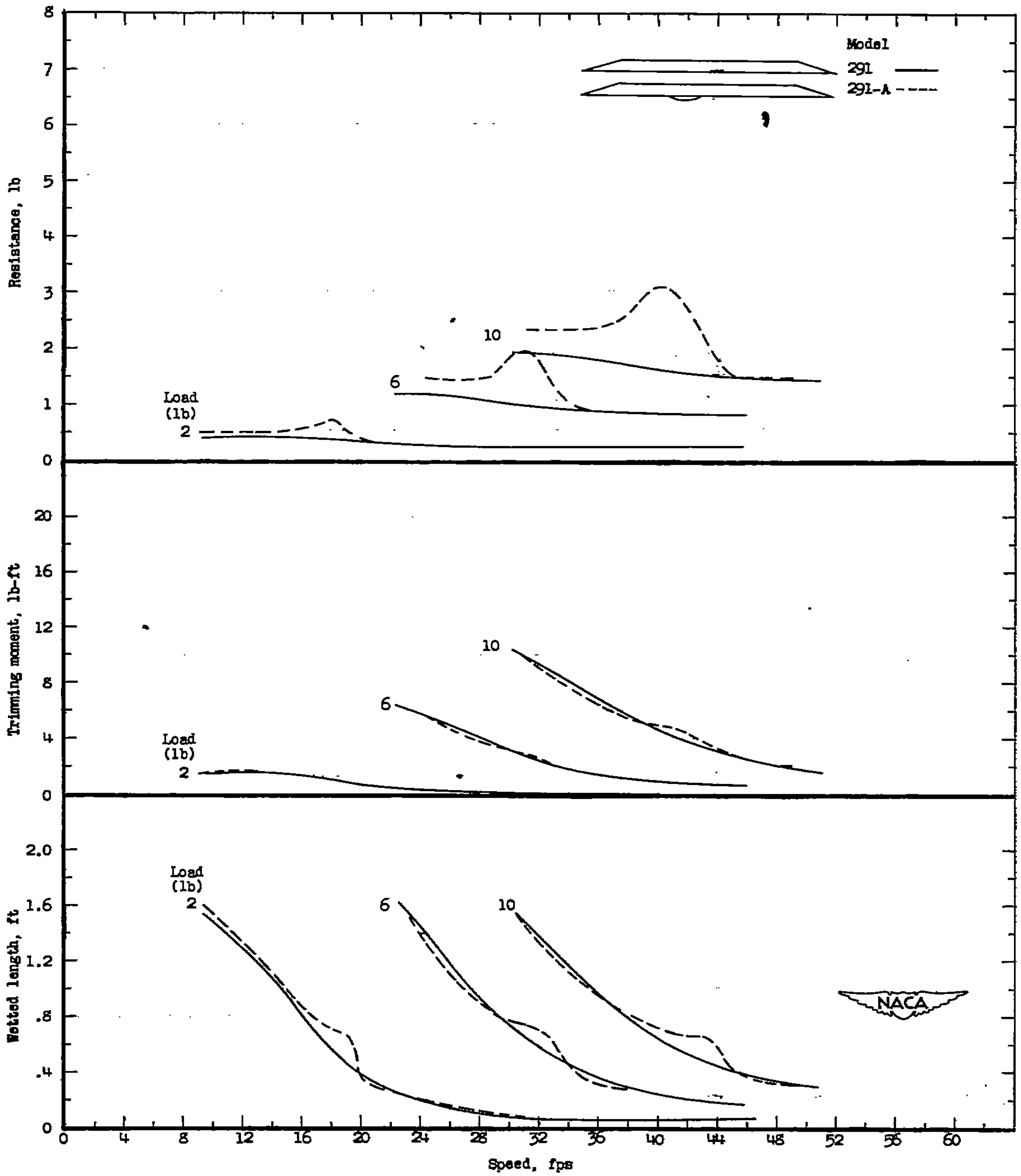
(a) Trim, 2°.

Figure 21.- General effect of wheel on the planing characteristics of a ski.



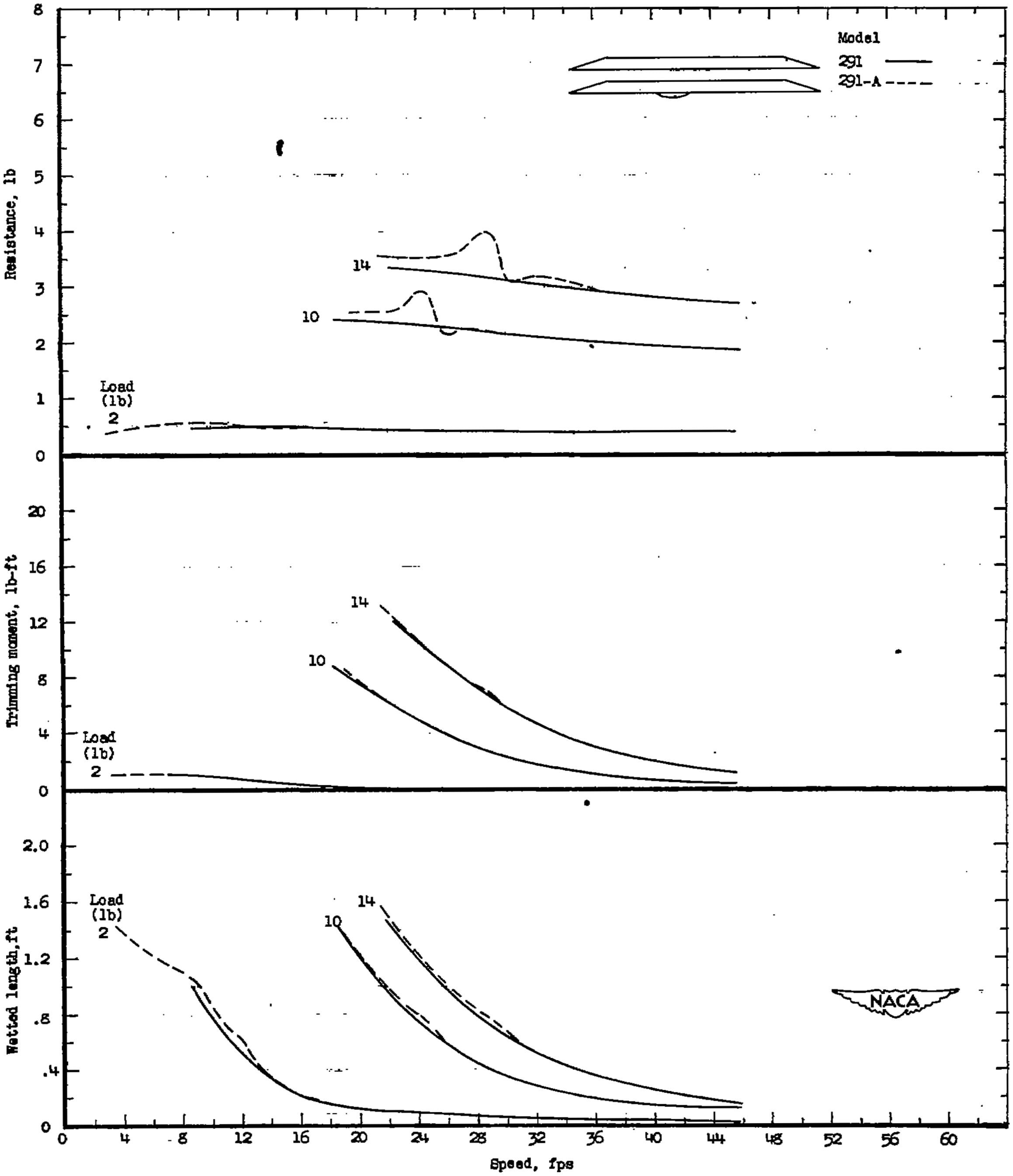
(b) Trim, 4°.

Figure 21.- Continued.



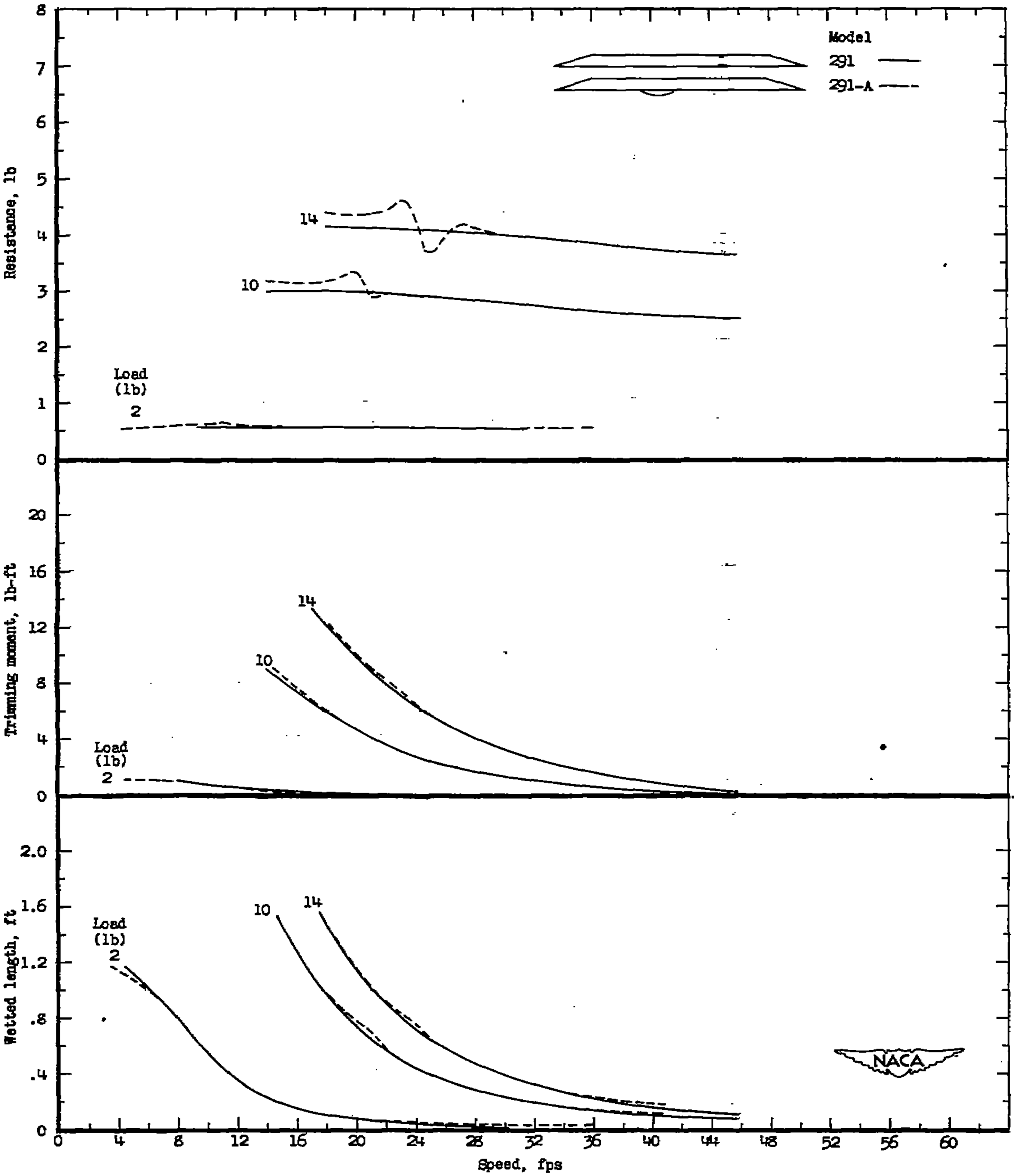
(c) Trim, 6°.

Figure 21.- Continued.



(d) Trim, 12°.

Figure 21.- Continued.



(e) Trim, 16°.

Figure 21.- Concluded.

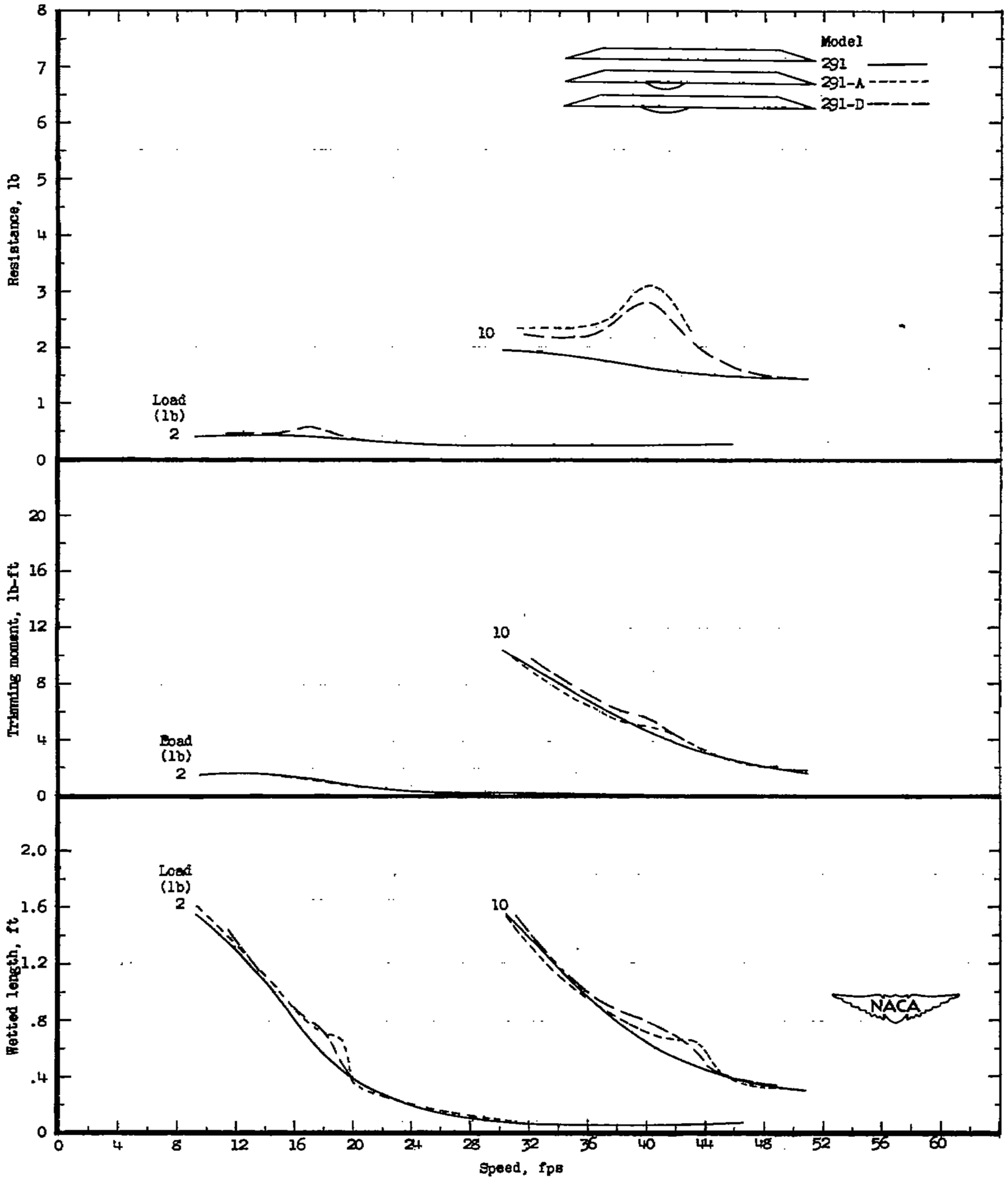


Figure 22.- Effect of diameter of wheel. Trim, 6°.

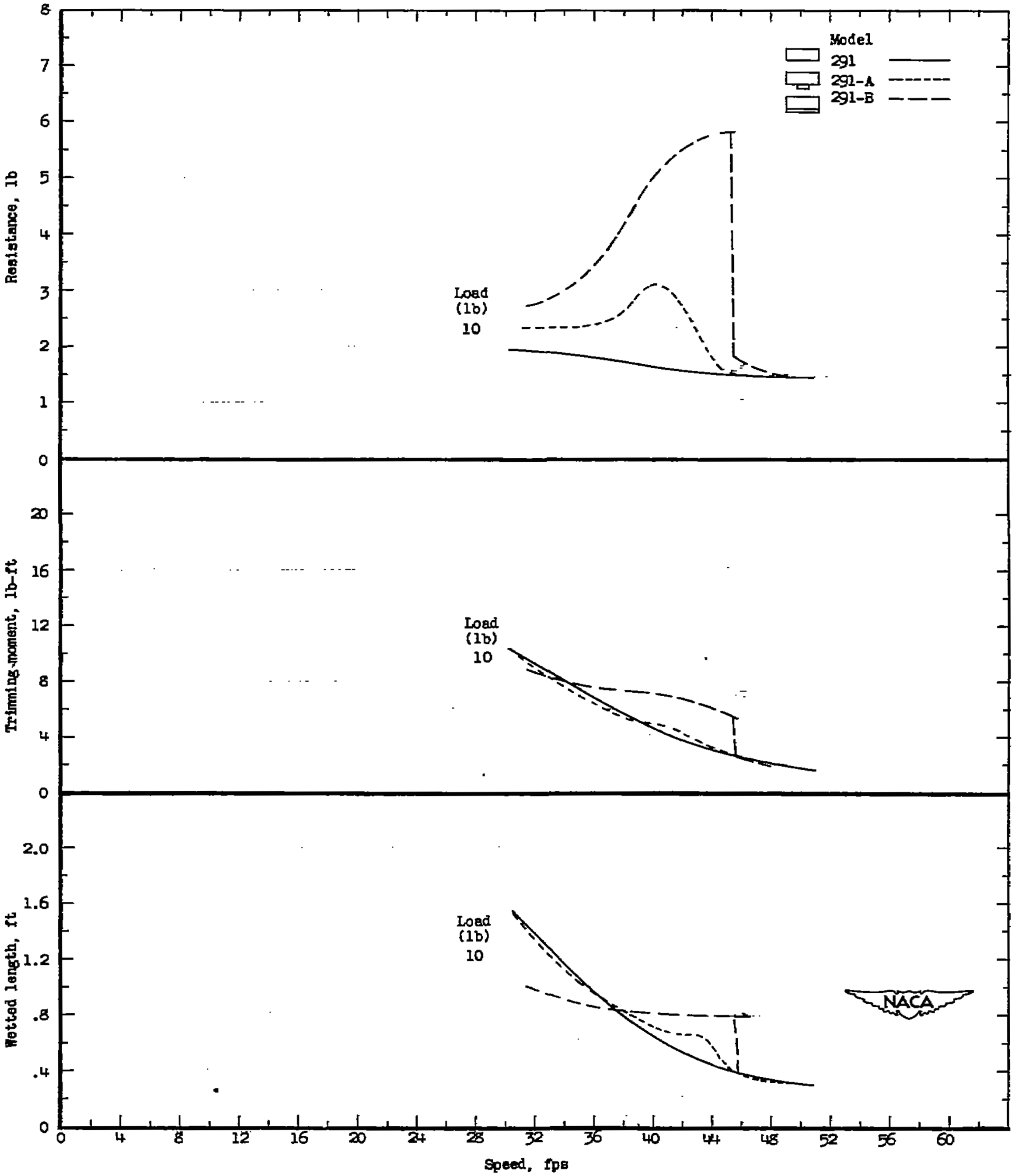


Figure 23.- Effect of width of wheel. Trim, 6°.

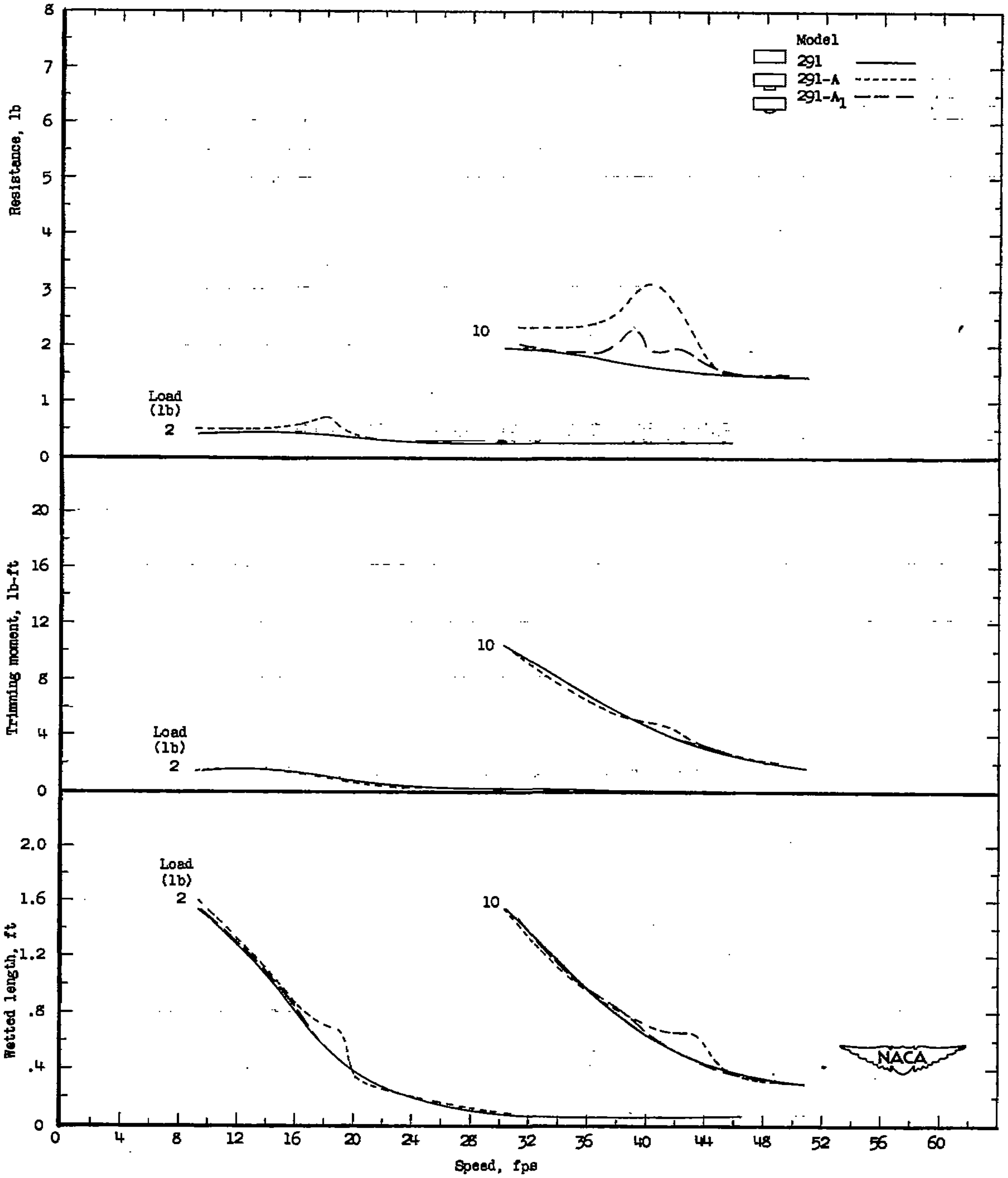


Figure 24.- Effect of cross-section shape of wheel. Trim, 6°.

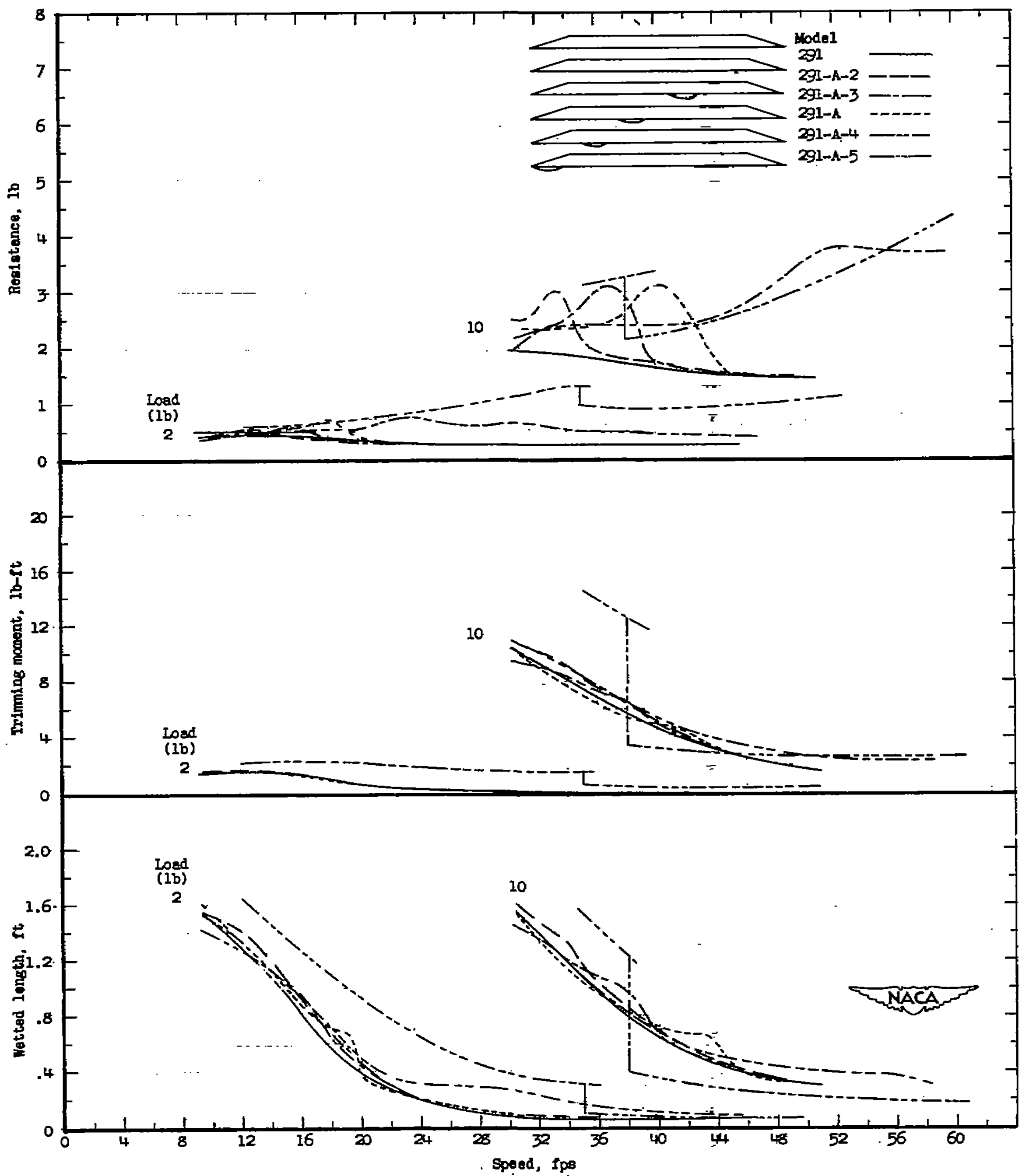


Figure 25.- Effect of fore-and-aft position of wheel. Trim, 6°.

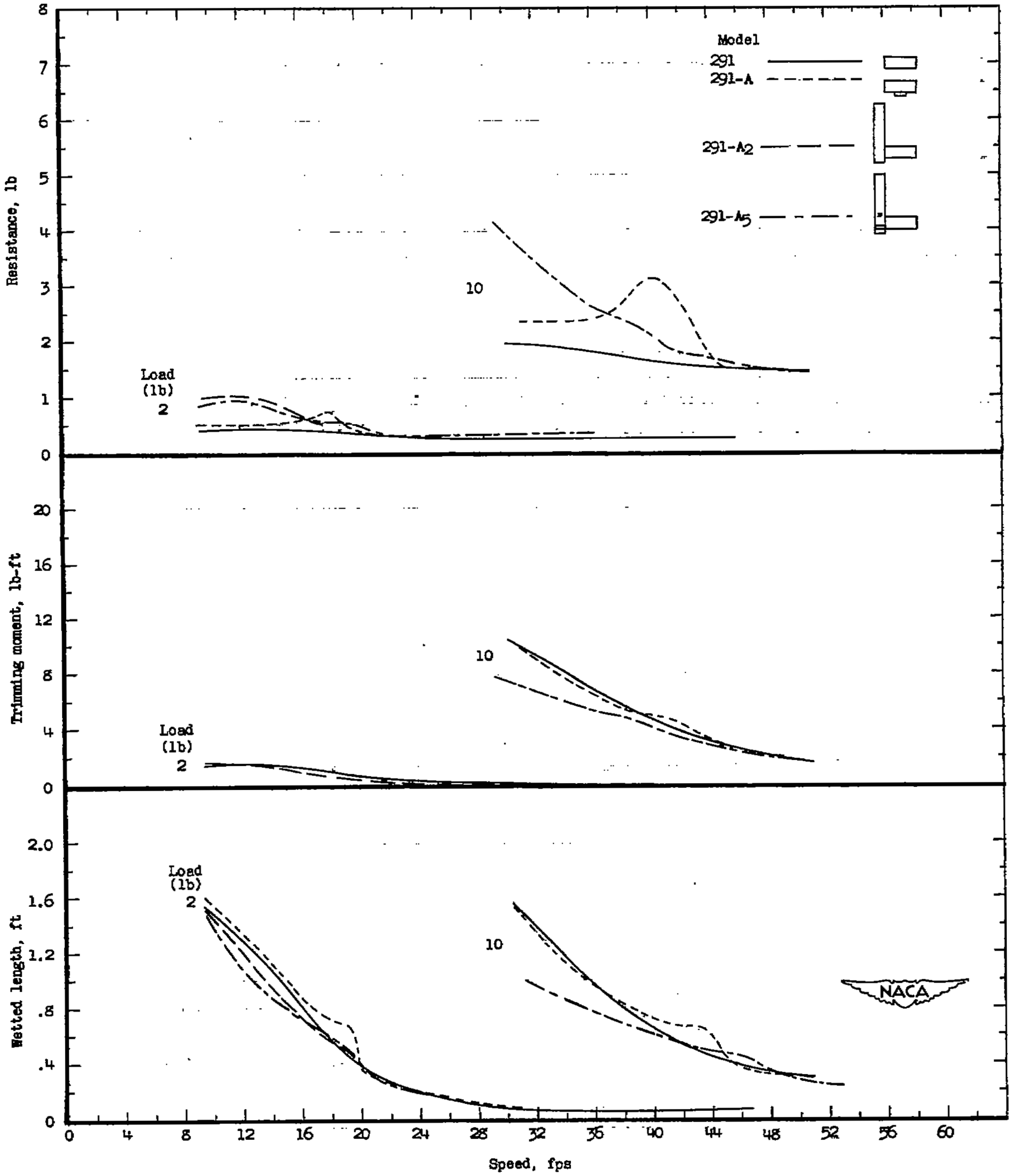


Figure 26.- Comparison of wheel on center line and on side of ski. Trim, 6°.

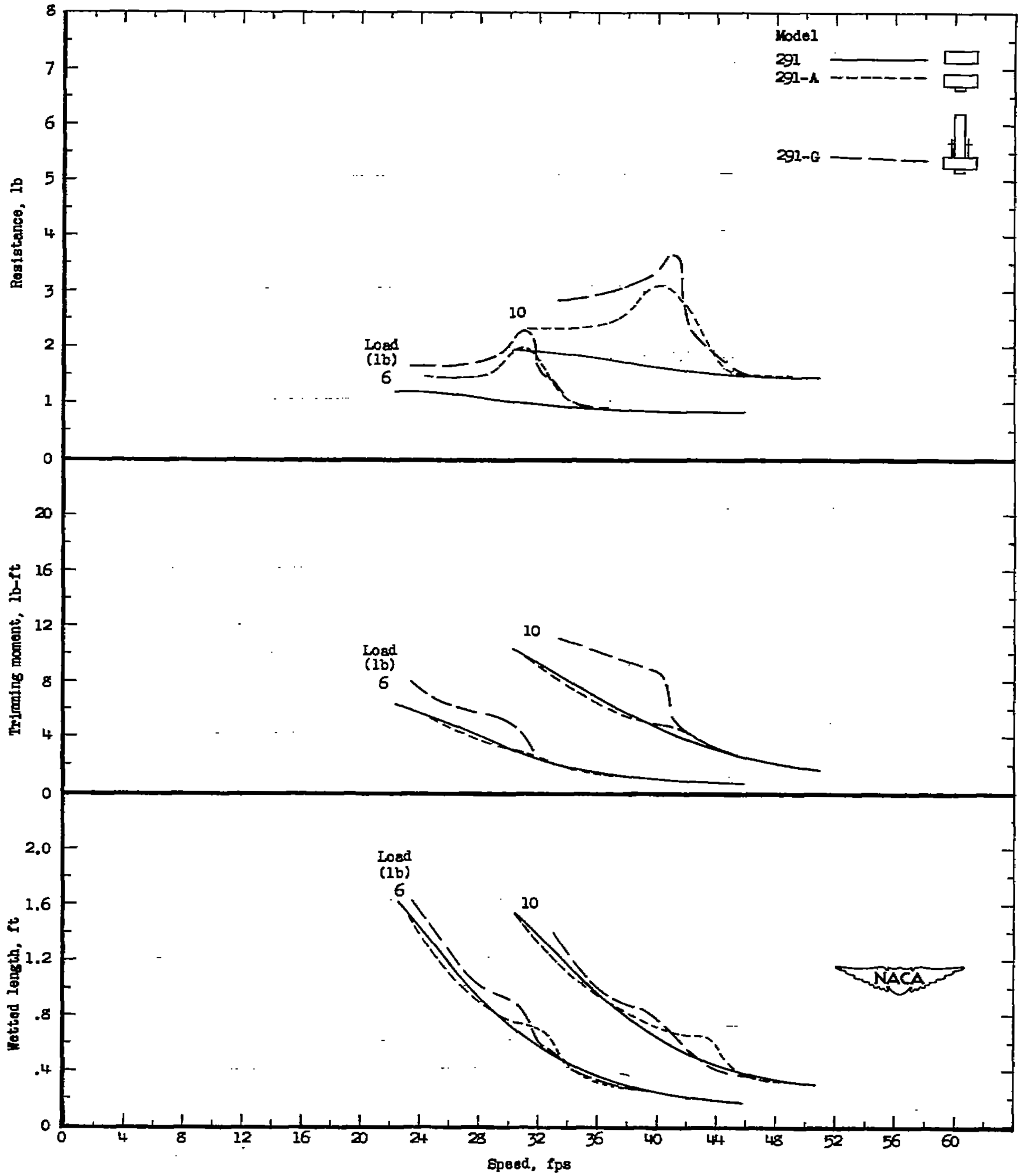


Figure 27.- Effect of gap between wheel and ski. Trim, 6°.

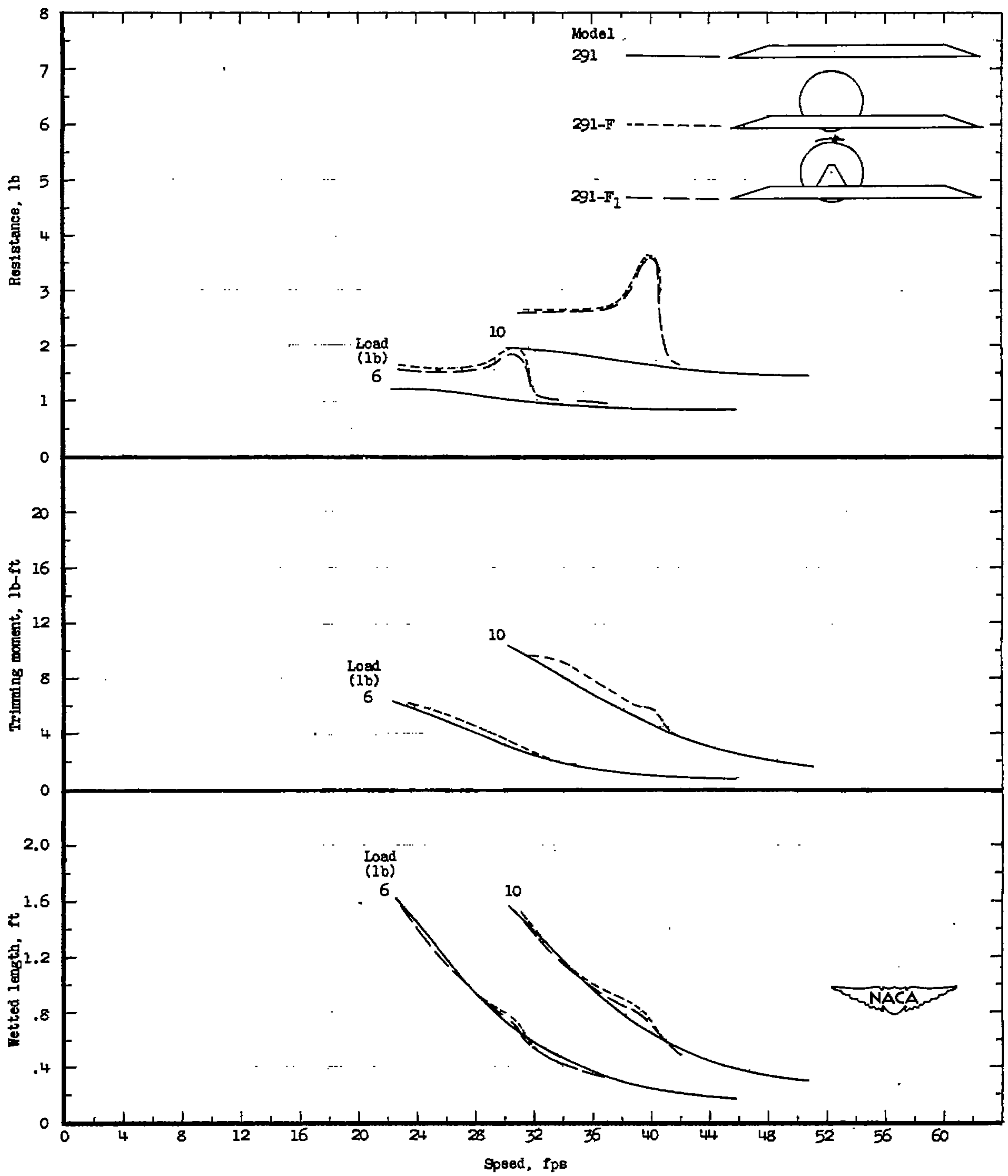


Figure 28.- Effect of rotation of wheel. Trim, 6°.

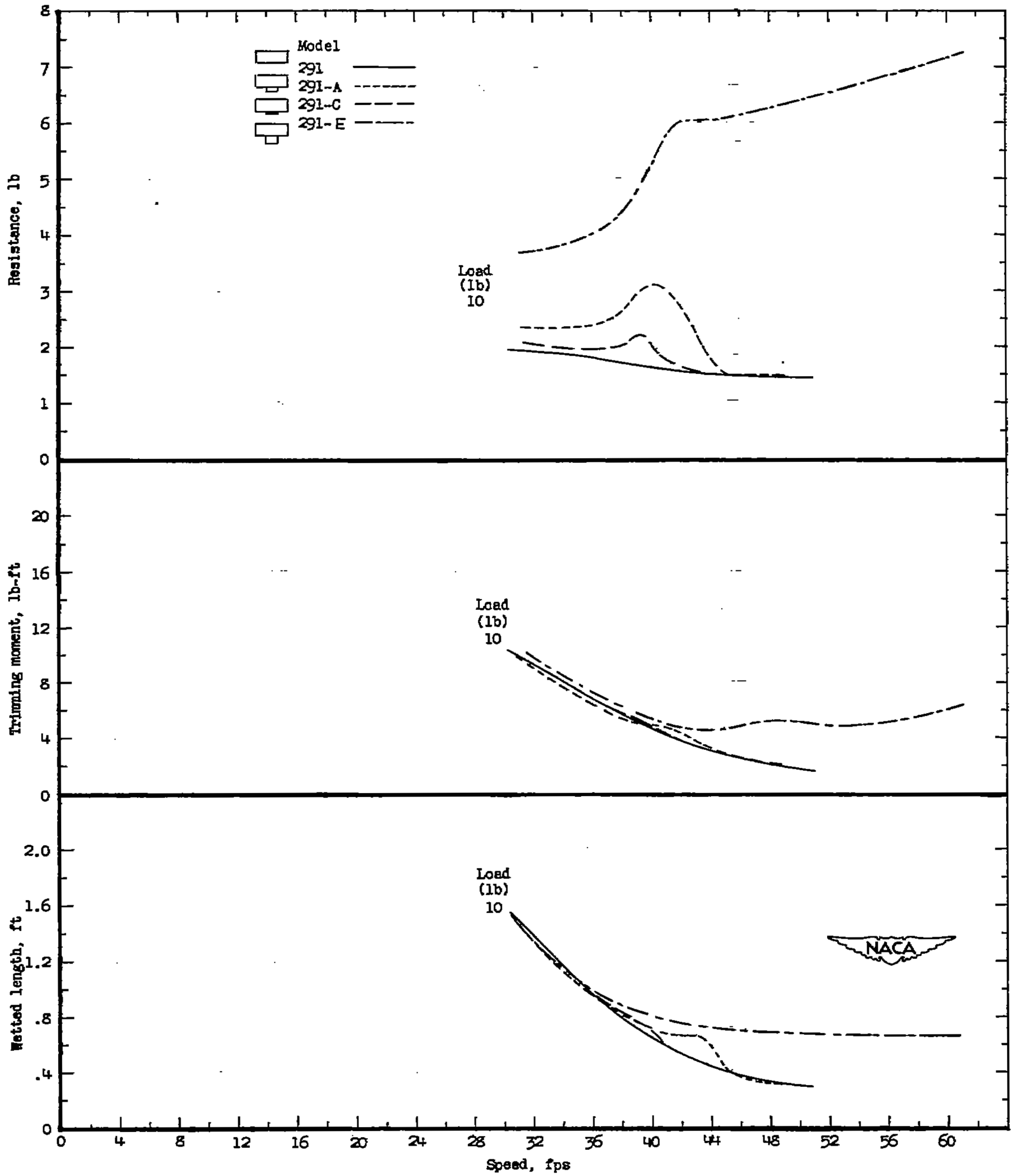


Figure 29.- Effect of protrusion of wheel. Trim, 6°.

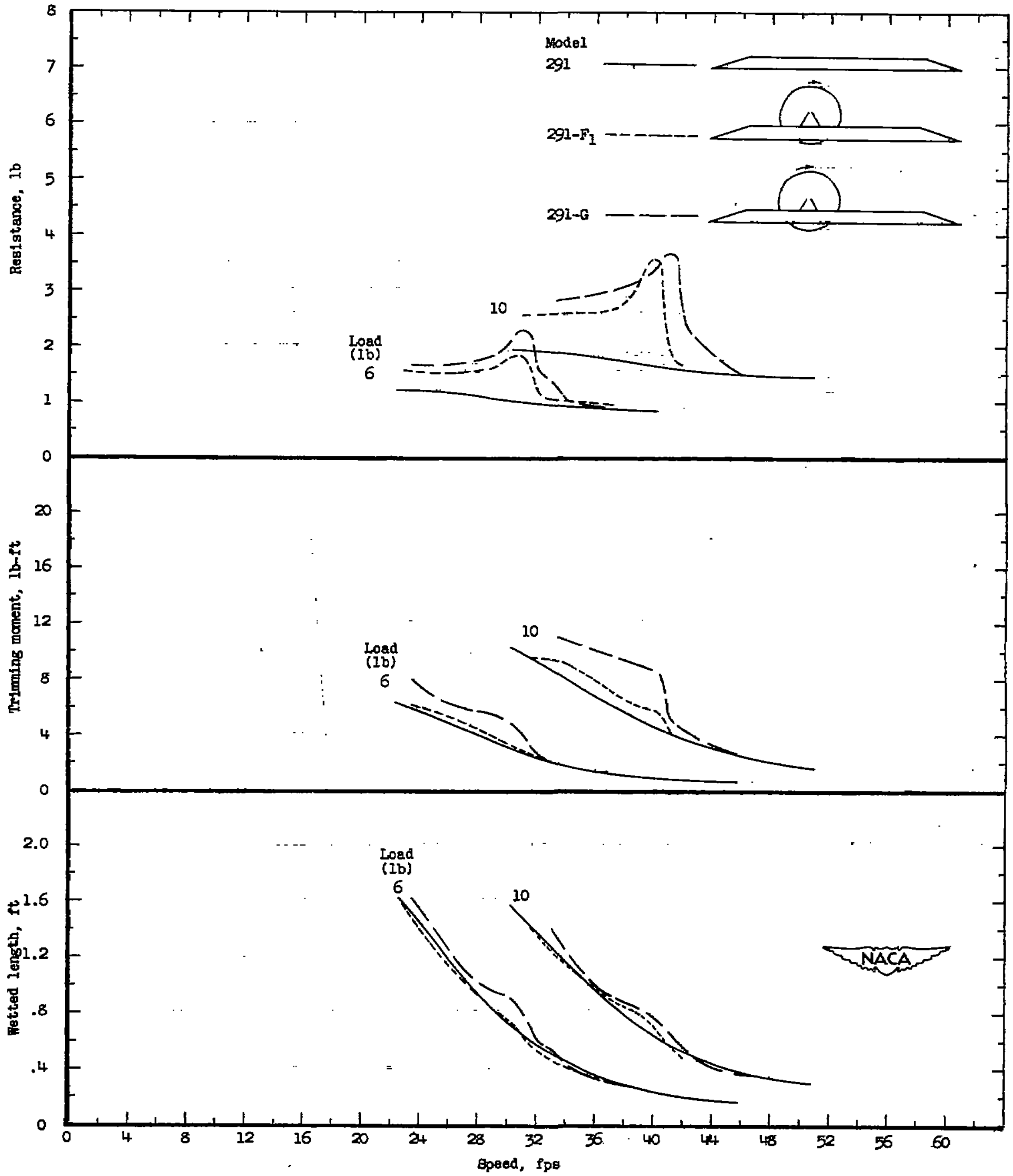


Figure 30.- Effect of protrusion of wheel with wheel free to rotate. Trim, 6°.

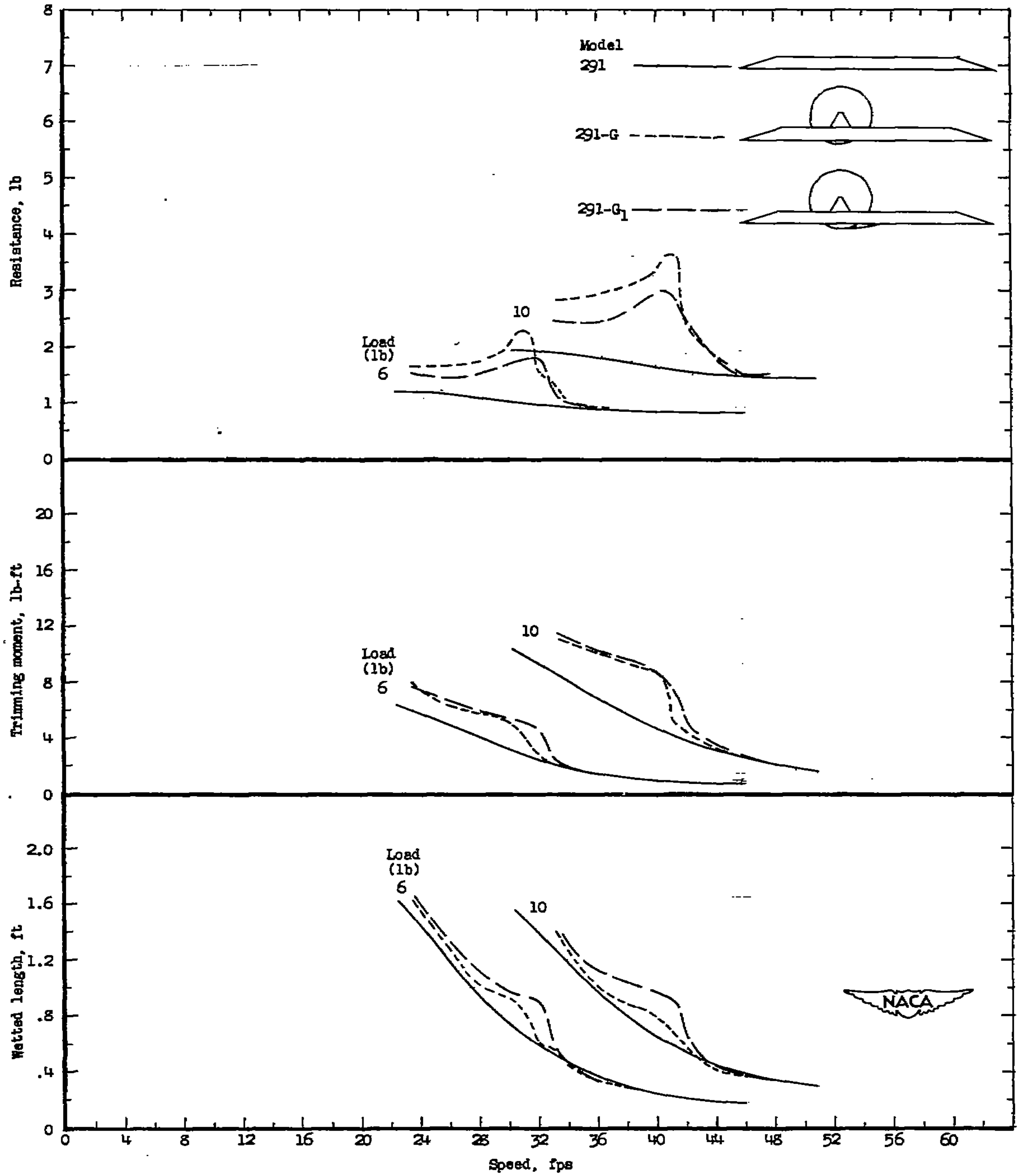


Figure 31.- Effect of fairing on bottom of ski forward of wheel. Trim, 6°.

SECURITY INFORMATION

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